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NEW PRODUCTS OF THE PETROLEUM INDUSTRY.*

BY

HUGH W. FIELD,

The Atlantic Refining Co.

The headlines of the nation's newspapers have been filled with accounts of the critical reconversion problems of most of our great industries. The petroleum industry, however, has been conspicuously quiet, yet it is well known that the wartime developments in this industry were tremendous. It is known that our forces, armed with mechanized equipment of a quality vastly superior to that of our enemies, never lacked the all-necessary petroleum supplies either in quality or quantity to do the critical job at hand. Very little is generally known of the nature of these warborne advances in petroleum refineries and how they were and are being thrown into step with a peacetime economy at a speed and efficiency that restored the motorist to a prewar basis almost overnight and will shortly advance the standard of enjoyment of petroleum products well beyond all preconceived levels.

It is the purpose of this discourse to take you through the gates of the refinery and give you a first hand glimpse of what has been happening during the last decade which has changed the operations of petroleum refining from those involving mainly rough physical separation by distillation to a complex well-integrated series of physical and chemical manufacturing operations involving the highest levels of modern chemistry and chemical engineering.

WHY THE PETROLEUM INDUSTRY GREW.

In order to get a clear understanding of *what* has happened in the petroleum industry, it is necessary to understand *why* it has happened

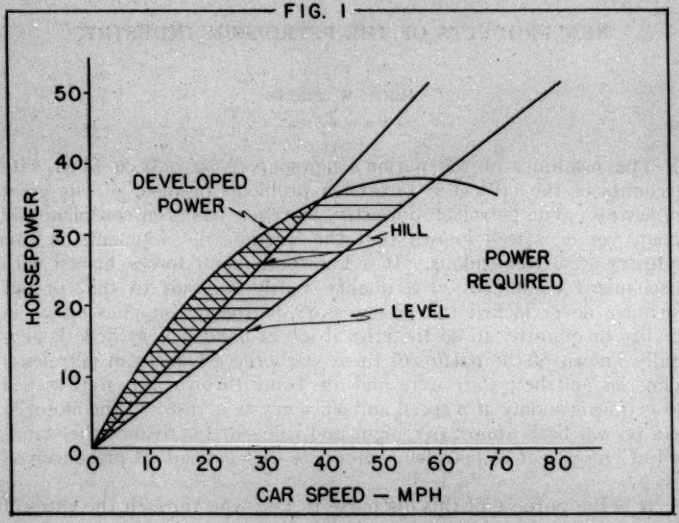
* Presented before The Franklin Institute, December 18, 1946.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

and to accomplish this we will do well to look back into history to trace the development pattern. Fortunately, our browsing through history will not take long because the industry does not have much history as measured by years. All of the significant items have occurred within the lifetime of most of us present.

The petroleum industry has had its real growth along with two other young industrial giants, the automotive industry and the aviation industry. Further, although many of the new operations and products which will come into our story later seem to have little or nothing to do with either of these industries, the responsibility for

FIG. 1



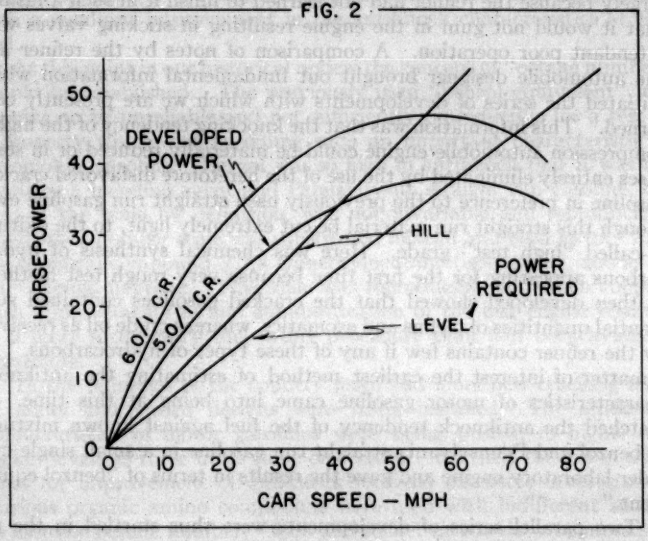
much of what has happened is closely tied with their growth. It all began a little over twenty years ago when the automobile engine designers stopped worrying about whether their engines would start and continue to run, and began to be worried by their sales departments for promotional stories along the line of getaway, pick-up, hill climbing ability, top speed and so on. These designers studied their engines and their cars and found many interesting facts a few of which we should examine.

Figure 1 is a plot of horsepower against car speed for a typical car of the time operating in high gear. The curve depicts developed power as delivered to the rear wheels plotted against car speed. The straight lines approximate power required to move the car at the corresponding

speed for level road operation and for uphill climbing on a reasonable grade, all wind conditions, fuel quality and loading, constant. It can be seen that this car has a top speed of 60 miles per hour on the level and has a reasonable amount of excess power for acceleration between the speed ranges of 15 to 50 miles per hour. However, on the upgrade climb the car will drop off to a top speed of 40 miles per hour and will have practically no high gear acceleration at lower speeds.

Figure 2 is the same basic plot with one additional curve, the developed power curve for the same car with the same engine modified only by an increase in compression ratio from say 5 to 1 to a ratio of 6.0 to 1—

FIG. 2



a minor design change. Now the car has a top speed of 70 miles per hour on the level road and has good acceleration in the broader range of 10–60 miles per hour. More important, its hill climbing ability is tremendously improved. On the same hill as previous it can maintain a top speed of 55 miles per hour and below this speed shows acceleration characteristics on the hill approximately as good as the previous model showed on the level road. Here was a direction for the engine designer to go and he started off that way and moved rapidly until he was stopped short by the fact that at the higher compression ratios his engines began to knock badly under load, particularly after the combustion chambers became fouled with the carbonaceous deposits which inevitably appear after several thousand miles of operation.

Now let us look at what was happening in the refinery during this time. Initially, gasoline was the very volatile hydrocarbon material "topped" from crude oil prior to running for the kerosine fraction used extensively for cooking and illuminating purposes. The demands of the automobile for this gasoline rapidly took it out of the by-product classification and the refiner was seeking ways and means of increasing gasoline production. He had discovered the thermal "cracking" process with which by the use of heat and pressure he could convert a large portion of the fraction of crude oil between the kerosine and the lubri-oil cuts into gasoline. But this "cracked" gasoline fell into ill repute, largely because the refiner had not learned to finish it in such a fashion that it would not gum in the engine resulting in sticking valves with attendant poor operation. A comparison of notes by the refiner and the automobile designer brought out fundamental information which initiated the series of developments with which we are presently concerned. This information was that the knocking tendency of the higher compression automobile engine could be materially reduced or in some cases entirely eliminated by the use of the heretofore disfavored cracked gasoline in preference to the previously used straight run gasoline even though this straight run material be cut extremely light, to the oldtime so-called "high test" grade. Here was chemical synthesis of hydrocarbons appearing for the first time because very rough test methods as then developed showed that the cracked gasolines contained substantial quantities of olefins and aromatics, whereas crude oil as received by the refiner contains few if any of these types of hydrocarbons. As a matter of interest the earliest method of estimating the antiknock characteristics of motor gasoline came into being at this time. It matched the antiknock tendency of the fuel against known mixtures of benzol and Pennsylvania straight run gasoline in a small single cylinder laboratory engine and gave the results in terms of "benzol equivalent."

Two parallel series of developments were thus startled in the refinery as a result of the move by the engine designers to higher compression motors. One series was aimed at removing or otherwise taking care of the then prevalent deficiencies of cracked gasoline with respect to gum forming tendencies, chemical instability and offensive odor. Processes to remove the gummy materials, soon identified principally as diolefins, from the cracked gasoline took the form of treatment with sulfuric acid and vapor phase treatment over activated fullers earth. The result of all these developments was the assumption by cracked gasoline of its rightful place as a desirable component of motor gasoline. Further, the development of various processes to convert the malodorous mercaptans, which appeared in the cracked gasoline as a result of decomposition of the heavy sulfur compounds in the heavier oils, to the

sweet smelling alkyl disulfides did much to occasion public as well as motor acceptance of this important motor fuel component.

The other series of developments which raced ahead at this time had to do with the production of cracked gasoline itself. Literally scores of thermal cracking processes and variations thereof were invented and many of them were patented. As special methods of fabrication were developed and new high temperature steel alloys were formulated thermal cracking operations were pressed to higher and higher conditions of severity with respect to pressure and temperature. This was because more severe cracking conditions produced more marked changes in the hydrocarbon structure of the cracked gasoline with a resultant improvement in the antiknock characteristics of this fuel.

At this point in our historical review the concept of "octane number" should be established. The previously used "benzol equivalent" was proving to be unreliable and not sufficiently reproducible for a test of a property which was becoming such an important characteristic of automobile gasoline. Benzol was so high in antiknock that it was too sensitive a blending agent and Pennsylvania straight run gasoline, the zero of the scale by definition, was not invariable and reproducible. The octane number scale was substituted instead and used as its "100" the chemical compound 2,2,4 trimethylpentane (iso-octane), and as its "0," normal heptane. This scale was reproducible and when coupled with improvements to and standardization of the test engine resulted in a more satisfactory fuel rating procedure than had been available heretofore.

In the refineries of the country more and more new cracking units of many and varied designs were being installed. The antiknock characteristics of motor gasolines were being pushed to higher and higher levels as these units came on stream. Further, the use of additives for improvement of antiknock received extensive investigation. Various organic amino compounds were used with indifferent success to increase octane number. Iron and nickel carbonyls were more successful from the octane number improvement standpoint but caused objectionable rust deposits within the engine. Finally, tetraethyl lead was discovered, proved satisfactory, and extensive manufacturing facilities were put into operation to help further the improvement in engine and fuel performance.

The "octane race" of the thirties was on in dead earnest. Automotive engine designers moved their compression ratios higher and higher getting, as a result, much more power and performance out of smaller engines. Figure 3 gives an interesting comparison for a representative passenger automobile.

From this it can be seen that during the thirties the performance characteristics of the typical passenger car of approximately the same

total weight improved considerably as a result primarily of the increase in compression ratio and the improvement in the quality of the motor fuel available for use in the higher compression engine.

At this point in our technical historical study the issues become somewhat obscure as so frequently happens when history is reviewed whether it be the history of people, cities or nations. The automobile engine designer had slowed in his advance to higher compression ratio due to the fact that the motoring public was reasonably happy, if not somewhat unsafe, with the car performance being obtained plus the very practical facts that design difficulties were being encountered at higher compression ratios due to the necessity for allowing room at

FIG. 3

YEAR	CAR	ENGINE		GASOLINE
	WEIGHT LBS.	COMPRESSION RATIO	BRAKE HORSEPOWER	OCTANE NO. REGULAR GRADE AVERAGE U.S.
1930	2930	5.15	64	60
1939	2934	6.32	85	71

top compression for the functioning of two valves and a spark plug and a tendency to rough operation at high compression. However, the petroleum engineer was now in the saddle. He had many new processes all lined up to produce and the refiner was now being urged by *his* sales promotion people to produce qualities in gasoline that could be talked about. The result was that the petroleum refiners began to run races between themselves to produce gasolines with qualities outstripping their competitors in spite of the fact that most of the automobile engines could not recognize differences in antiknock above its basic octane requirement. At the time, this race was scientifically invigorating but economically rather silly. In retrospect however, it was probably one of the best things that ever happened to our country

in that it set the fundamental pattern for a technology that produced, during World War II, on a stupendous tonnage basis synthetic organic chemicals without which the war would have stretched through a much longer and burdensome period.

EFFECT OF FUEL COMBUSTION PROGRESS ON THE REST OF THE AUTOMOBILE.

Before proceeding further with the later developments in motor fuel processing it will be well to stop and examine the results of all of this engine and fuel development work on the other parts of the automobile and on petroleum product requirements for these parts. Increasing the power output of the engines produced greater loads on the engine connecting rod and main bearings with the result that many engine designers developed engines in which alloys of cadmium-silver and copper-lead were used for bearings instead of the conventional tin-lead (babbitt)which had been used heretofore. From the standpoint of bearing loads these materials were excellent but they immediately gave the petroleum refiners many headaches since the sulfur compounds present in the lubricating oil and the condensate from combustion chamber "blow-by" to the crankcase plus the acids produced by normal oxidation of the lubricating oil caused severe and rapid bearing deterioration. The corrosion attacked the lead and cadmium in these bearings resulting in weakening of the bearing alloy and early noisy operation of the engine. Protection of these bearing materials was critical and the challenge to the petroleum research laboratories started a new trend in lubricating oil development. This trend has resulted in the progressive addition to lubricating oils of a long series of additives. Initially additives were used to take care of bearing corrosion problems. Later, additives were developed to add to the lubricating oil higher film strength characteristics. Presently, additives are being incorporated in the oil to furnish, in addition to the previous benefits, properties to prevent buildup of sludge deposits in the crankcase and to increase engine life heretofore shortened by internal rusting between periods of operation.

As engines increased in power and the streamlining of automobiles resulted in smaller wheels and lower floorboards a redesign of the differential drive in the rear axle came about in efforts to lower the driveshaft to avoid the necessity for a tunnel in the rear floor. This gave rise to the use of hypoid gearing to drop the driveshaft below the center line of the rear axle. Hypoid gearing worked out very admirably from the standpoint of chassis design but necessitated an extensive amount of research in petroleum laboratories to develop a rear axle lubricant for for these new type gears. The previous type of gearing, namely, spiral bevel gears, operated on the principle of rolling friction and a conventional heavy lubricant protected the faces of the gear teeth quite satisfactorily. The hypoid gear, on the other hand, operates on the prin-

ciple of sliding friction and conventional lubricants could not give protection, with the result that the hypoid rear axles were scuffing severely because of failure of the oil to stay between the gear teeth. By the use of additives specially developed for the purpose, the oil companies quite promptly were able to furnish lubricants which had the proper combination of surface tension and wetting porperties to stay in place on the gear teeth of heavily loaded hypoid gears.

The smaller wheels previously mentioned, the higher speeds resulting from greater engine power and the general adoption of internal expanding four-wheel brakes, raised another problem for the petroleum industry in lubricating the wheel bearings. The wheels were turning faster, creating higher operating temperatures in the bearing and greater centrifugal force which tended to throw the grease out of the bearings through the oil retaining ring into the braking system causing malfunctioning of the brakes. Grease compounding quickly received a complete overhauling in order to furnish a wheel-bearing lubricant which would maintain its consistency at high temperatures of operation, neither separating into oil and soap with resultant loss of oil and clogging the bearing with soap, nor changing in physical characteristics as the temperature increased to a point where the grease would leave the bearing as the result of excessive softness.

General chassis lubricants also had to be restudied. All the previously mentioned developments were making cars run with less noise. Changes in spring-hanger design had increased the bearing loads on spring shackles so that there was an increased tendency for the shackles to squeak and with less noise competition the squeaks were more noticeable. New chassis lubricants were developed which would pump readily through the automatic chassis lubricating pumps being installed in the service stations and would stay between the bearing surfaces in spite of heavy impact loading and in spite of the tendency for splashed water from the highway to wash this grease away. This particular development, incidentally, is probably one of the most ingenious feats of compounding that the industry has done and is probably the least known generally.

CHANGING PETROLEUM REQUIREMENTS OTHER THAN AUTOMOTIVE

During this period under discussion the automobile, although acting as a pacesetter, was not the only requirement which was causing rapid changes in petroleum technology. The aviation industry which had even more to gain from power from smaller engines was stepping out ahead in requirements for high octane, high chemical stability fuel. The aviation engine designer increased compression ratio with the attendant advantages previously discussed, reached the mechanical limitation to high compression posed by necessity for valve and spark plug clearances and engine roughness and then moved on to even

higher levels in antiknock requirements by adopting the principle of supercharging. The supercharging approach to this problem is interesting and deserves further examination. If compression ratio cannot be increased readily, another way to get the same effect from a given engine is to pack more air and fuel into the cylinders by forcing it in under external pressure, rather than letting the engine draw it in by the vacuum created on the suction stroke. This development, started mildly by the automobile designer and adapted mainly for racing car engines, really went ahead at a tremendous pace when the aviation engine designers started to use it. While the superchargers built for racing car engines operated with only a few inches of water "boost pressure" the aviation engine designer moved ahead to the point where during World War II combat aircraft equipped with exhaust driven turbo superchargers actually delivered a boost pressure in the range of 60" of mercury or about 2 atm. increase. This development threw a tremendous burden on the petroleum industry for high antiknock fuel and, as will be mentioned later, the industry responded by adapting their newer processes and developing specialized processes in order to produce the required volumes of aviation gasoline having performance characteristics well in excess of 100 octane.

Another type of engine was becoming important and giving the petroleum research laboratories critical problems to solve. This was the Diesel engine initially developed for propelling ships, later for long-distance truck hauling, and now becoming very important as a source of power for railway locomotives. The Diesel engine, unlike the gasoline engine, does not depend on a spark for ignition but depends on auto ignition induced by the heat and pressure created by the compression stroke of the piston. It is obvious that an operating cycle of this type necessarily changes as the chemical composition of the fuel changes and, from the standpoint of general comparison, the type of compounds which are included in motor gasoline and to some extent in aviation gasoline to improve antiknock characteristics are the type of compound which had a deleterious effect on the starting and ignition qualities of the Diesel fuel, particularly for high speed truck and railway Diesel engines. Thus a technical contrast is presented in which the best Diesel fuel was found to be a carefully refined fraction obtained directly from high grade crude oil whereas high grade motor gasoline is obtained by processes in which the various fractions of crude oil must be molecularly rearranged by severe thermal and catalytic cracking and these products blended with synthetic products of complicated structure obtained from alkylation, polymerization, etc.

Most of the comments made with respect to automobile engine lubricating oil hold for lubricating the Diesel engine, except that whatever is done to the oil to improve its inherent characteristics must be greatly emphasized for the Diesel. Most high speed Diesels run under

much more severe conditions of loading, combustion roughness and high temperature operation than most automobile engines.

In industrial fields a new tempo of development has been evident. Machine tools, industrial machinery, electrical equipment, heavy fuel oil consuming equipment, all have had their speeds, loads and requirements for continuity of operation increased at a rapid pace. The petroleum industry has conducted research successfully to furnish petroleum products required to meet these demands. Complete details on the many ramifications of the changes in the petroleum industry's industrial requirements have no place in this review, but the order of magnitude of changes has been of the same degree as that depicted for automotive and aviation industries.

NEW PROCESSES WHICH LEAD TO NEW PRODUCTS.

In 1939 your speaker was requested to present to the Refining Division of The American Petroleum Institute a paper which attempted to systematize and catalogue the many new processes which were under development at that time. This paper was somewhat whimsically entitled "Petroleum-ization—1940" since it dealt with such previously little known or unused processes as dehydrogenation, isomerization, polymerzation, aromatization, alkylation, etc. The paper attempted to place these various new processes on the checkerboard of petroleum refining to determine which ones were competitive, which were complementary, and which should be considered for use as various refinery situations arose. Due to the undeveloped state of some of these processes at that time, a large amount of forecasting based on personal opinion was woven into the pattern presented. However, subsequent events, specifically the War, forced the hasty commercialization of most of these processes substantially along the lines predicted and since this pattern is fundamental to our examination of new products it is presented here.

Definitions and Descriptions. A certain number of definitions and descriptions will be useful in our study of the situation; and if these definitions do not agree exactly with the organic textbook, it should be remembered that they were drafted for "petroleum-ization" rather than for the broad field of general organic chemistry.

Catalyst. A catalyst can be defined as a substance which, although present during a chemical reaction, apparently does not enter into the reaction but causes, by its presence, a change in the conditions under which that reaction occurs. Thus catalytic reactions offer a possibility for product control by selective acceleration of certain reactions which, in the opinion of many, is the most important phase of this new refining technique.

Hydrogenation. The hydrogenation process adds hydrogen to the hydrocarbon molecule. Hydrogenation may be either non-destructive or destructive. In the former, hydrogen is added to the molecule

only if, and where, unsaturation with respect to hydrogen exists; thus the boiling range of the product is substantially the same as that of the charge to the process. In the latter, operations are carried out under conditions which result in rupture of some of the hydrocarbon chains (cracking); the hydrogen adding on, in general, where the chain breaks have occurred. A change in boiling range results from this type of hydrogenation, the degree of change depending on the operating conditions. Non-destructive hydrogenation is generally a low-temperature low-pressure operation, whereas destructive hydrogenation operates at high temperature and high pressure. Catalysts are employed in almost all hydrogenation processes.

Dehydrogenation. The general use of this term is so broad that it is practically useless. For example, the cracking of gas oil in an early batch still involved dehydrogenation. For the purpose of this discussion, the term will be limited to operations on material in the gasoline boiling range, or lighter, and considered in two categories, as was done for hydrogenation, i.e., non-destructive and destructive. Non-destructive dehydrogenation is defined as the removal of hydrogen from the hydrocarbon molecule without the cracking which would change significantly its boiling range. Destructive dehydrogenation removes hydrogen from the molecule, but is accompanied by chain rupture to some degree. Catalysts are employed for the non-destructive dehydrogenation, but the destructive dehydrogenation may be carried out either with or without catalysts—depending on the degree of selectivity desired.

Polymerization. Broadly speaking, polymerization can be considered as the linking of two or more hydrocarbon molecules to form one molecule having a longer carbon chain and a higher boiling point. Here again the definition must be narrowed to make it useful, because the tar produced when gas oil is cracked in a conventional cracking coil is the result of polymerization. Polymerization, as practiced intentionally, at the present time is confined to hydrocarbons having four carbon ātoms or less to the molecule (butane and lighter), and links them together under conditions which result in the product being predominantly within the gasoline boiling range. The operation can be carried out either catalytically or thermally. The catalytic process operates at relatively high pressures, but at moderate temperatures, and only the unsaturates in the charge react. The thermal process operates at high pressures and high temperatures, but reacts both unsaturates and saturates—due in part, but not entirely, to thermal dehydrogenation taking place in the heating coil as the charge is brought to operating temperature.

Alkylation. If any saturated hydrocarbon molecule is deprived of a hydrogen atom and then united with another hydrocarbon molecule through the bond where the hydrogen atom was removed, alkyl-

ation has been accomplished. The broad definition of this term leaves us nowhere, but one of the specific alkylation processes in which interest is at a high pitch at the present time unites isobutane (a branched-chain compound) with a butene (unsaturated branched- or straight-chain compound) to produce practically pure iso-octane. The operation is carried out at low pressure and low temperature, and requires a catalyst. Another example is the process which produces cumene. In this process propylene is reacted with benzol to produce isopropyl benzene, a valuable aviation blending agent.

Desulfurization. In the broad sense, this term is self-defining, but here it will be considered as applying to the removal of sulfur from material within the gasoline boiling range. Chemical desulfurization, using either sulfuric acid or caustic soda, has been practiced for many years. There is, however, a definite feeling that destructive chemical desulfurization is on the way out; so, for the purpose of this summary—which is concerned chiefly with the new catalytic processes—the definition will be narrowed to identify processes which decompose the sulfur-hydrocarbon compounds in the gasoline, and evolve the sulfur as hydrogen sulfide or possibly as sulfur dioxide.

Isomerization. Inasmuch as saturated hydrocarbons can exist as either straight- or branched-chain compounds, and as the branched-chain compounds in the gasoline boiling range have higher antiknock qualities than the straight-chain compounds (e.g., iso-octane vs. normal heptane, the 100 and 0, respectively, of our antiknock scale), interest in controlled changing of straight chains to branched chains (isomerization) increased sharply as practicable methods were discovered. Isomerization, as now available for our study as an isolated process, is confined to butane and pentane conversion to the corresponding isocompounds; but inasmuch as the extremely high octane-number increase obtained during certain catalytic-dehydrogenation operations on gasoline can best be accounted for by assuming some isomerization to have occurred, it is the opinion in many quarters that catalysts and conditions will be found eventually which will extend isomerization as a controlled process into the broad gasoline boiling range.

Aromatization. For present purposes let us define aromatization as the conversion of saturated hydrocarbons to aromatic hydrocarbons, e.g., conversoin of hexane to benzol, heptane to toluol, etc. Processes using catalysts at relatively high temperatures and moderate pressures have accomplished such conversions with surprisingly high yields.

Catalytic Cracking and Reforming. As mentioned previously, cracking involves dehydrogenation of the type defined as destructive. In the rupturing of the hydrocarbon chains, there are created fragments which are extremely active chemically. In the course of reacting to attain chemical stability, these fragments apparently, to some degree, engage in practically all of the reactions which we have been discussing.

The use of a catalyst during cracking has the interesting effect of decreasing the amount of polymerization to tar and at the same time encouraging aromatization and isomerization of the cracked fractions in the gasoline boiling range. As a result, material of high antiknock value is produced. In catalytic reforming a different effect is sought. Here aromatization and isomerization are encouraged by different operating conditions and catalysts, but every effort is made to suppress

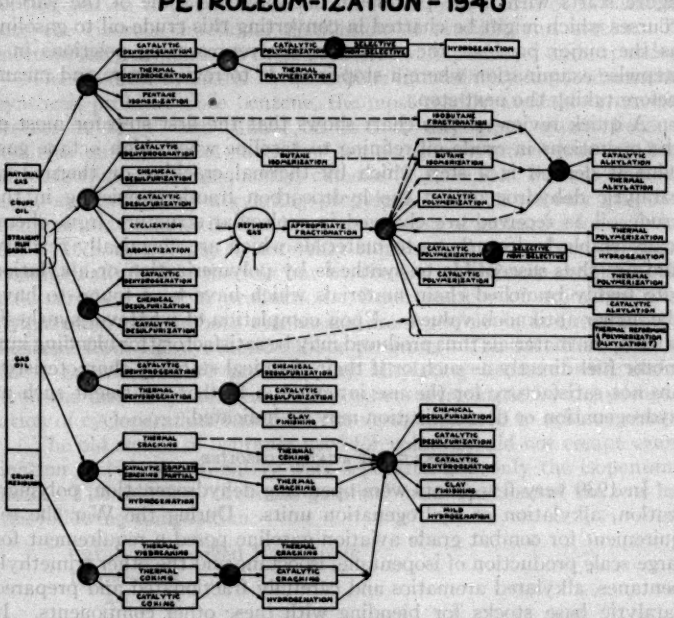


FIG. 4.

the chain rupture which would cause excessive conversion of gasoline to gas. In figure 4 catalytic reforming is classified as dehydrogenation, but merely for convenience, and does not infer that the dehydrogenation phase is considered predominant.

Coking. The operation of coking, whether thermal or catalytic, consists of heat-treating heavy hydrocarbons, usually crude residuum or cracked tar, in order to increase the ultimate yield of gasoline from the crude. Heavy hydrocarbons are low in hydrogen-carbon ratio; gasoline is relatively high in this same ratio. The conversion, there-

fore, necessitates the throwing out of carbon (coke) as a means of adjustment of this ratio. Catalytic coking, as contrasted with thermal coking, results in less coke "throwout" for a given conversion, possibly due to the fact that gasolines of relatively high aromatic content have a lower hydrogen-carbon ratio than non-aromatic gasolines, and lower carbon "throwout" would suffice for the adjustment in hydrogen-carbon ratio necessitated by this type of conversion.

Figure 4 is taken directly from the above mentioned paper. This figure starts with crude petroleum and presents some of the various courses which might be charted in converting this crude oil to gasoline as the major product, the shaded circles representing positions in a stepwise examination where a stop is made to review ways and means before taking the next step.

A quick review of this chart shows that the first step for most of the operations in crude oil refining to gasoline where high octane gasoline is desired is a step which by thermal cracking or thermal or catalytic dehydrogenation the hydrocarbon fractions existing in the crude oil as received are changed in molecular structure from chemically stable hydrocarbons to materials which are chemically reactive and are thus susceptible to synthesis by polymerization or alkylation into highly branched chain materials which have been found to have the higher antiknock values. Upon completion of whatever synthesis is used, the materials thus produced may be satisfactory for blending into motor fuel directly as such or if their chemical stability characteristics are not satisfactory for the use intended, a further treatment such as hydrogenation or desulfurization may be indicated.

COMBAT GRADE AVIATION GASOLINE.

In 1939 very few plants were operating dehydrogenation, polymerization, alkylation or hydrogenation units. During the War the requirement for combat grade aviation gasoline posed a requirement for large-scale production of isopentane, isooctane and the other trimethylpentanes, alkylated aromatics and carefully fractionated and prepared catalytic base stocks for blending with these other components. It was only by tailormaking the fuel in this fashion that the characteristics required by the modern aviation engine could be met completely. The fuel had to be 100 octane under normal cruising conditions, it had to be chemically stable under storage conditions in all parts of the world and had to respond with an apparent antiknock value considerably in excess of 100 to permit maximum power at top supercharge boost pressure and rich mixture for plane takeoff conditions.

The important development of catalytic cracking enabled the production of superior aviation base stocks. In these processes, oil is cracked in the presence of a catalyst which results in the formation of appreciable quantities of aromatics and isoparaffiins. Only a very

small amount of olefins, which are undesirable for aviation gasoline, are formed in contrast to older thermal cracking processes which produce large amounts of olefins.

Three chief sources of isoparaffins were utilized; the most important being the product known as "alkylate" which is produced by combining low molecular weight olefins and isoparaffin hydrocarbons. The second most important source of isoparaffiins is the polymerization of two low molecular weight olefins (product known as codimer) followed by hydrogenation to obtain an isoparaffin. A third source of isoparaffins was the rigorous fractional distillation of straight run stocks. To meet military demands all these processes were perfected and expanded.

The need for aromatic hydrocarbons immediately imposed another synthesis problem since benzene, the most readily available aromatic, freezes at 40° F. and cannot be used to any great extent because aviation gasoline must meet low temperature requirements for high altitude flying. Consequently, cumene (F.P. −141° F.) was immediately synthesized by alkylating propylene (a waste refinery gas) and benzene and became the first important source of aromatics for aviation fuel. It is interesting to note that cumene had never been produced commercially before the war but by the end of the war about 500,000 gal. per day were in production. Other sources of aromatics were xylenes and toluene both synthesized from petroleum and excess ethyl benzene from the synthetic rubber program. The fact that some of these aromatics were produced by alkylating benzene with olefins (cumene and ethyl benzene) while others were made by dehydrogenation of cycloparaffins illustrates the versatility used to achieve results.

The old source of pentanes used for volatility did not escape examination and these ultimately were separated and only the isopentanes used. The chemical "aviation gasoline" near the close of the war had the following composition:

- Catalytic Cracked Base Stock
- Isoparaffins
  - Alkylate
  - Hydrogenated Codimer
  - Isohexanes and Isoheptanes (fractioned from straight run naphtha)
- Aromatics
  - Toluene
  - Xylenes
  - Ethyl Benzene
  - Cumene
- Isopentane

This mixture of components with the addition of tetraethyl lead was known as 100/130 grade aviation gasoline. It has a performance

rating of 130 under take-off conditions and a rating of 100 under flight conditions. This fuel made available 30 per cent. more power over the old fuel for take-offs and short bursts of speed during actual combat. At the start of the war the production of 100 octane aviation gasoline was approximately 40,000 bbls./day. At the close of the war 100/130 grade aviation fuel was being produced in excess of 500,000 bbls./day.

INDUSTRIAL PROCESSING MATERIALS FROM PETROLEUM.

In the field of what are known as processing materials from petroleum there continue to be new products and applications. In fact there are few articles that do not utilize petroleum in some form in their manufacture. It is said that over 30 basic industries employ petroleum in their manufacturing operations. Individual applications are numerous. It is in the classes of processing materials and manufactured chemicals that petroleum products number into hundreds and unit values are greatest.

One of the processing materials made from petroleum in largest volume is paraffin wax with which we are all familiar in the form of bread wrappers, waxed paper, paper milk bottles, and candles. A newcomer to the field of waxes is a material known as microcrystalline wax which is tough and pliable at low temperatures and extremely resistant to water. Microcrystalline waxes had been made prior to the war but their real value was not appreciated until the advent of problems created by the war. Microcrystalline waxes were first called "amorphous waxes" because they were believed to be non-crystalline. It was later found that they contained minute wax crystals and they became known as microcrystalline waxes. Small arms and rations were packaged in containers utilizing these waxes in their construction. Microcrystalline waxes have been used for liners of metal cans and drums to resist the action of beer, wines, and acids. The developments in microcrystalline wax created large demands and it is continuing to be necessary for the industry to bend every effort in order to supply the required quantities.

In most uses of petroleum waxes, they are applied in a molten condition. Wax can also be applied in the form of a wax emulsion which is a fine suspension of wax in water containing a suitable dispersing agent. The use of wax emulsions is attaining increased importance. The armed forces used thousands of yards of tent cloth, cotton duck, and mosquito netting that had been treated with wax emulsion. Wax emulsions impart a water repellent finish to the individual fibers. The treatment has practically no effect on the appearance and "feel" of the fabric and because of openings remaining between the fibers, adequate ventilation is assured.

Rust preventives are another group of products designed for war service. Protection against rust has always been a problem but it

was made more difficult by military requirements. Metal objects both large and small had to stand shipping on boats all over the world where exposure to salty air and high humidity was ideal for rapid rust formation. Practically all metal articles used by the armed forces were coated with one of many rust preventives developed, and in many instances, the rust preventive was subsequently removed before use of the article, adding to the problem. Practically all of these rust preventives contained a petroleum base. The knowledge gained here should find ready application in preserving metal machinery such as farm tools and machinery frequently stored for long periods without use.

Two new developments in the field of asphalt are prefabricated airport runways and asphalts resistant to stripping from stone by water. In the first development burlap is saturated with asphalt, coated with small stones and rolled up as is common asphalt roll roofing for shipment. It is put down by employing a 50 per cent. overlap and cementing together with an asphalt cut-back. A large amount of this was employed by the armed forces. Asphalts resistant to stripping from stone contain additives to increase the adhesion tension between the stone and asphalt. Such asphalts will coat stone in the presence of water. The use of these materials will result in better and longer life roads.

Other developments in processing materials derived from petroleum have included plasticizers and softeners for synthetic rubbers, special oils that are heavier than water for mosquito control, and high refractive index oils for use in examining quartz crystals which are cut into oscillators to control wave length in radar and radio equipment.

SYNTHETIC RUBBER FROM PETROLEUM

Much has been written about this country's synthetic rubber industry claimed by some before the atomic bomb announcement to be the greatest technical achievement of all time. Large quantities of butadiene and styrene were needed to make the government's all-purpose rubber known as GR-S. There are several methods of producing butadiene from petroleum but the best methods consist of dehydrogenating certain C_4 hydrocarbons to form butadiene. As an example of the commercialization of butadiene production the government owned plant of the Neches Butane Products Company producing butadiene from petroleum is rated at 100,000 tons of butadiene per year and has produced at a rate far in excess of this. New uses for butadiene can be expected now that this material is commercially available and at least one such product (butadiene monoxide, a chemical intermediate) has already been announced.

Styrene production also required for GR-S rubber is carried on by the chemical industry by alkylating benzene with the petroleum olefin ethylene to form ethyl benzene which is converted to styrene by

dehydrogenation. Ethylene is recovered from refinery gases or produced by cracking a petroleum hydrocarbon such as propylene.

Butyl rubber, another very important synthetic rubber, is a 100 per cent. petroleum product and a 100 per cent. American development. It is synthesized from isobutylene, a petroleum hydrocarbon obtained from cracking processes, and a small amount of a diolefin such as isoprene. These two hydrocarbons are converted into butyl rubber at temperatures of approximately −150° F. by a continuous process. This development filled the nation's need for heavy duty inner tubes at a time when natural rubber was cut off and GR-S (butadiene styrene rubber) was unsatisfactory. Butyl rubber in some respects is superior to natural rubber; namely, better resistance to oxidation and lower permeability to the passage of gases. Butyl rubber inner tubes have proved superior to natural rubber tubes and butyl is expected to have an excellent future. It should find new uses in electrical insulation, waterproof fabrics, and mechanical goods.

PLASTICS FROM PETROLEUM.

In the field of plastics there have been some notable products derived from petroleum hydrocarbons. Among the newer petroleum plastics are polyethylene resins, allyl plastics, and polyvinylidene chloride resin. Polyethylene resins are a 100 per cent. petroleum hydrocarbon resin produced by polymerizing ethylene itself. Their production was announced in 1944 by the duPont Company and then independently by the Carbide and Carbon Chemicals Corporation. Polyethylene plastics are flexible and tough over a wide range of temperatures, have exceptional electrical properties, are resistant to moisture penetration, and are chemically inert. They are thermoplastic and can be made into thin sheets and filaments. Polyethylene has been used primarily in electrical insulation for radar equipment. It can be expected to find many uses in a peacetime economy. Its production represents another major technical achievement.

Allyl plastics are based on allyl alcohol which is derived from propylene. In 1942 two allyl resins were announced, one by an oil company (diallyl phthalate) and the other (now allymer CR-39) by a chemical company. These plastics are reported to make excellent coating materials for cans and metal containers, one being reported to be less brittle and harder than glass and harder than any other transparent plastic. Its uses have been strictly military. The resins have properties unique to themselves which should make them find ready markets. Allyl alcohol and chloride will doubtless find many other uses in chemical synthesis.

Some time ago a chemical company announced a resin produced from the monomer vinylidene chloride which is a derivative of ethylene and therefore, is of interest to the petroleum industry. It differs from

the older vinyl cholride monomer in that two chlorine atoms have been substituted for hydrogen atoms in the ethylene molecule instead of one. This plastic is very tough and resistant to solvents. It also has a very high tensile strength and can be made into strong filaments. Taking advantage of these properties, expected uses include seat covers, filter cloths, house screening, fishing lines, hose connections and flexible tubing.

Older resins which are derived at least in part from petroleum and were greatly expanded for war uses are the polyvinyl resins, acrylic resins (Lucite and Plexiglas), ethylcellulose, and phenolics employing alkylated phenols.

Among important chemicals newly derived from petroleum and announced during the war is phthalic anhydride, produced by oxidizing ortho xylene (previous production has been from naphthalene from coal tar). One petroleum company has built a plant to manufacture this chemical which is used in the synthesis of plastics, plasticizers, and insect repellants. Another company has announced a new synthesis for carbon bisulfide from methane and sulfur. This chemical is used in the manufacture of viscose rayon, solvent extraction processes, and in the manufacture of chemicals used in ore separation and for vulcanizing rubber. Its older synthesis was from coke and sulfur.

DETERGENTS FROM PETROLEUM.

For many years both oil soluble and water soluble soaps have been produced from petroleum mainly as byproducts from the treating of oils for industrial or medicinal purposes. Just prior to the war a demand arose for synthetic detergents or wetting agents which would be superior to either the byproduct soaps or soaps made by saponification of fatty or vegetable oils. Research carried out in petroleum laboratories resulted in development of processes for synthesizing such detergents from petroleum hydrocarbons and commercialization of these processes was quite rapid. During the war all of such production was under allocation to such uses as incorporation in G.I. all purpose soap for use in all kinds of water, penicillin manufacture and many other critical uses. Since the war, requirements have increased largely for incorporation in industrial and household cleansers. In addition, many of the products have been improved by utilizing plant facilities and processes developed for aviation gasoline or toluene manufacture. The petroleum soap of today is a complicated chemical synthetic controlled in properties to meet very exacting requirements and a far cry from the older types of byproduct soap.

WHAT HAS HAPPENED TO THE REFINERY.

As we have traced refinery history in the preceding discussion many new processes have been developed to handle the requirements

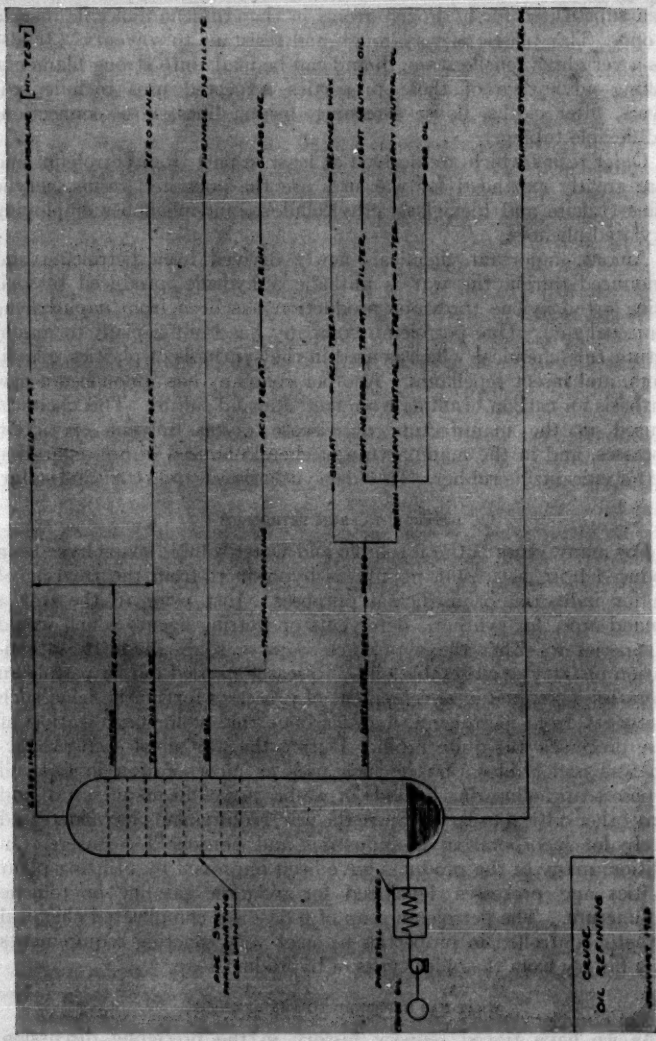

GASOLINE [40° TEST]
ACID TREAT
KEROSENE
ACID TREAT
PARAFFINE DISTILLATE
GASOLINE
ACID TREAT
RESIN
SLACK
ACID TREAT
REFINED WAX
LIGHT NEUTRAL
TREAT
FILTER
LIGHT NEUTRAL OIL
HEAVY NEUTRAL
TREAT
FILTER
HEAVY NEUTRAL OIL
RED OIL
CRUDE STOCKS FOR OIL
GASOLINE
KEROSENE
PARAFFINE DISTILLATE
RED OIL
PARAFFINE DISTILLATE RESIDUUM
RED OIL
CRUDE OIL REFINING

FIG. 5.

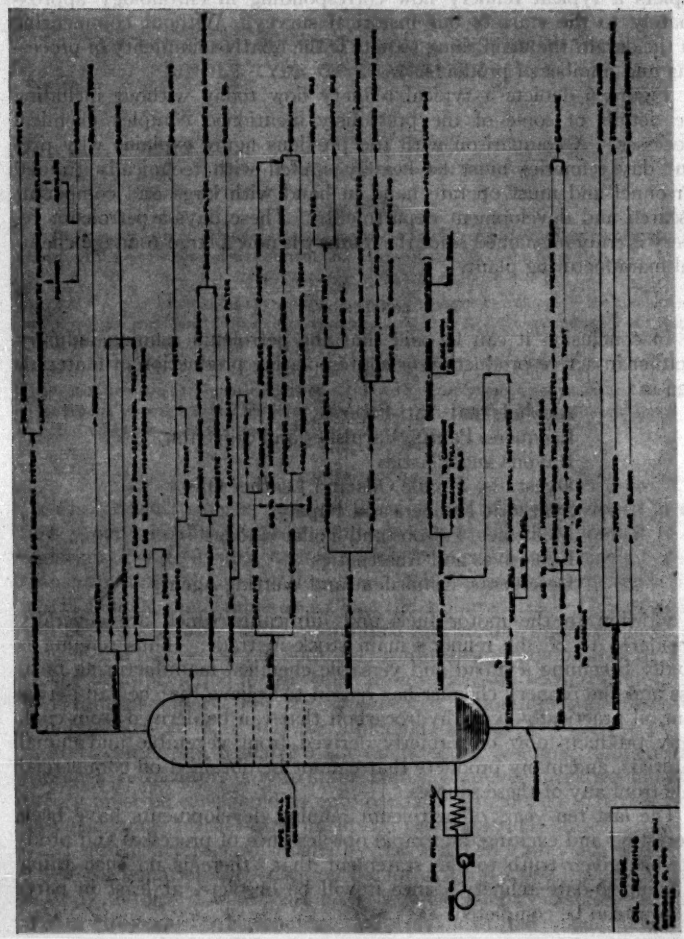


FIG. 6.

for the many new and improved petroleum products now in demand. The process flow of a refinery has almost become a maze. Figure 5 depicts a typical refinery flow corresponding in chronology approximately to the start of our historical survey. Without commenting on the details the main thing to note is the relative simplicity of processing and number of products.

Figure 6 depicts a typical refinery flow today without including the details of some of the previously mentioned complex chemical processes. A comparison with the previous figure explains why present day refineries must be heavily staffed with technically trained personnel and must operate hand in hand with large and competent research and development departments. These days a petroleum refinery is truly misnamed since the refinery is now a large tonnage chemical manufacturing plant.

CONCLUSION.

In conclusion it can be said that the petroleum refining industry is either in active production or contemplating production of materials used in:

Alcohols and Anti-Freezes
Lacquers, Paints, Varnishes and Solvents
Rayons and Plastics
Dyestuffs, Textile Oils and Leather Oils
Synthetic Rubbers and Paper
Medicines, Poisons and Toilet Goods
Explosives and Anesthetics
Detergents, Emulsifiers and Wetting Agents

in addition to the motor fuels and lubricants which are generally considered to be the refiner's main stock in trade. Thus refining is rapidly becoming a broad and versatile chemical manufacturing business and the refinery chemist has reason to believe that he can derive from oil practically every hydrocarbon that can be derived from coal, many products now or formerly derived from vegetable and animal materials, and many products that cannot be obtained on commercial scale from any of these sources.

The last ten years of petroleum refining developments have been interesting and exciting, and rapid obsolescence of processes and products has given truth to the statement that "there is no such thing as an up-to-date refinery" since it will be obsolete, at least in part, before it can be completed.

AN EQUATION OF STATE FOR A SYSTEM WITH A SINGLE TYPE OF TRANSFORMATION.

BY

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ABSTRACT.

Based on theory of a previous paper, the writer has developed an equation of state for a system with a single type of transformation. This equation is of the form

$$h = A + Bv + Cp + Dpv - T(E + Fv + Gp + Hpv),$$

where $h = \epsilon + pv$ is the total heat, p the pressure, v the specific volume, T the temperature, and p, v, T are considered independent variables. A, B, C, etc., are constants for the system. The latent heat at constant (p, T) is given by

$$\lambda_{p,T} = (v_2 - v_1)(\partial h/\partial v)_{p,T} = (v_2 - v_1)[(B - TF) + p(D - TH)].$$

These equations are checked with data on saturated and superheated ammonia, and the agreement is good to within a few tenths of a per cent. Also, checks with data on saturated and superheated steam show agreement within several per cent.

1. INTRODUCTION.

The present paper is an application of the theory developed in the first paper * in this JOURNAL, and consists in the development of an equation of state for a system in which there exists but a single type of transformation. This equation of state will be general, in the sense that it will include metastable as well as the stable states. This equation will be checked with data on ammonia and steam, where we have extensive and precise data in both the saturation and superheated regions.

The transformation for the saturation region will be that from liquid to saturated vapor. For the superheated region the transformation will be $2NH_3 \rightleftharpoons N_2 + 3H_2$ for ammonia, and $2H_2O \rightleftharpoons 2H_2 + O_2$ for steam. Since the available data on pressure, volume, temperature, total heat, etc., apply only to stable states, whatever check we find with theory must be considered as only partial. It is hoped that this work may encourage further experiments on the metastable states.

A similar attempt was made by the writer in a previous paper (1). There the equation was based on the form $S = f(p, v, T)$, where S is the entropy and p, v, T were considered the independent variables. Certain points with regard to the characteristics of S in a three-dimensional space have arisen which will be taken up in a later paper. In the present paper we shall use the form $h = f(p, v, T)$, where $h = \epsilon + pv$ is the total heat.

* *J. F. I.*, **243**, 1, 1.

2. DEVELOPMENT OF THE EQUATION OF STATE.

The thermodynamic system is to manifest but a single type of transformation over the range of pressures, temperatures and volumes which we are to consider. For such a system the writer has shown that characteristic thermodynamic functions exist which require three independent variables for their complete determination; the complete determination is to mean that metastable as well as stable states are to be included in their realm. In the present development we shall concentrate our attention on the total heat expressed as

$$h = \epsilon + pv, \tag{1}$$

where $h = H/M$, $\epsilon = E/M$, $v = V/M$; H is the heat content (or total heat), E the internal energy, V the volume, and M the mass of the *entire* system.* p is the equilibrium pressure of the entire system. Write

$$h = f_1(p, v, T) = f_2(p, x, T), \tag{2}$$

where x is the ratio, by weight, of the transformed state to the total weight of the system. The functions f_1 and f_2 are assumed to be continuous and single-valued within the range $0 \leqq x \leqq 1$.

Differentiating (1), we have

$$dh = \left[\left(\frac{\partial \epsilon}{\partial v}\right)_{p,T} + p\right]dv + \left[\left(\frac{\partial \epsilon}{\partial p}\right)_{v,T} + v\right]dp + \left(\frac{\partial \epsilon}{\partial T}\right)_{p,v} dT. \tag{3}$$

Assume that the transformation process may be carried out in the following three ways: (1) with p, T = constant; (2) with v, T = constant; and (3) with p, v = constant. The first case is familiar to us when applied to a liquid-vapor system. In this case the latent heat, $\lambda_{p,T}$, is independent of x, and is a single-valued continuous function of p, T. Assume the same to hold for a single gaseous system, where $\lambda_{p,T}$ will be the heat of dissociation. Write

$$\lambda_{p,T} = \left(\frac{\partial \epsilon}{\partial v}\right)_{p,T} (v_2 - v_1) + p(v_2 - v_1) \tag{4}$$

or

$$\frac{\lambda_{p,T}}{v_2 - v_1} = \left(\frac{\partial \epsilon}{\partial v}\right)_{p,T} + p, \tag{5}$$

where v_1, v_2 are the specific volumes for $x = 0$ and $x = 1$, respectively; each of these specific volumes is assumed to be a continuous, single-valued function of p, T only.

The second case will involve the latent heat $\lambda_{v,T}$ and we shall assume the transformation to proceed from p_1 at $x = 0$ to p_2 at $x = 1$ at con-

* To include both phases in the case of liquid-vapor, and the associated and dissociated components in the case of a single gaseous phase.

stant v, T. This process can be readily visualized from the kinetic theory viewpoint. Following the analogy of the first case, assume that $\lambda_{v,T}$ is independent of x, and that $\lambda_{v,T}$, p_1 and p_2 are single-valued, continuous functions of v, T. Write

$$\lambda_{v,T} = \left(\frac{\partial \epsilon}{\partial p}\right)_{v,T} (p_2 - p_1) \tag{6}$$

or

$$\frac{\lambda_{v,T}}{p_2 - p_1} = \left(\frac{\partial \epsilon}{\partial p}\right)_{v,T}. \tag{7}$$

The third case is not as close to our laboratory experience as the first two; however, for the sake of mathematical symmetry we shall assume here a latent heat $\lambda_{p,v}$. From the viewpoint of kinetic theory, this transformation process may be explained as follows. Consider the volume to be held constant. If the temperature is increased, the increase in kinetic energy of the molecules would produce an increase in pressure, *provided the number of molecules remained constant.* If, however, we assume that during this rise in temperature x were decreased (i.e., a partial association to occur) so that p remained constant, the resulting process may be realized. Write

$$\lambda_{p,v} = \left(\frac{\partial \epsilon}{\partial T}\right)_{p,v} (T_2 - T_1) \tag{8}$$

or

$$\frac{\lambda_{p,v}}{T_2 - T_1} = \left(\frac{\partial \epsilon}{\partial T}\right)_{p,v}, \tag{9}$$

where T_1, T_2 correspond to the states $x = 1$ and $x = 0$, respectively. We shall assume $\lambda_{p,v}$, T_1 and T_2 to be continuous, single-valued functions of p, v, and $\lambda_{p,v}$ to be independent of x.

Substituting (5), (7) and (9) in (3), we have

$$dh = \frac{\lambda_{p,T}}{v_2 - v_1} dv + \left[\frac{\lambda_{v,T}}{p_2 - p_1} + v\right] dp + \frac{\lambda_{p,v}}{T_2 - T_1} dT$$

$$= \left(\frac{\partial h}{\partial v}\right)_{p,T} dv + \left(\frac{\partial h}{\partial p}\right)_{v,T} dp + \left(\frac{\partial h}{\partial T}\right)_{p,v} dT. \tag{10}$$

Thus

$$\left(\frac{\partial h}{\partial v}\right)_{p,T} = \frac{\lambda_{p,T}}{v_2 - v_1} = \theta(p, T), \tag{11}$$

$$\left(\frac{\partial h}{\partial p}\right)_{v,T} = \frac{\lambda_{v,T}}{p_2 - p_1} + v = \mu(v, T), \tag{12}$$

$$\left(\frac{\partial h}{\partial T}\right)_{p,v} = \frac{\lambda_{p,v}}{T_2 - T_1} = \nu(p, v). \tag{13}$$

Integrating the last three equations, we have

$$h = v\theta(p, T) + \phi(p, T), \tag{14}$$

$$h = p\mu(v, T) + \chi(v, T) \tag{15}$$

$$h = T\nu(p, v) + \psi(p, v), \tag{16}$$

each of which is a linear equation between h and one independent variable.

A complete equation of state should define h for each point in the (p, v, T) space. In the analysis below we shall develop an explicit equation of state in the following manner. First, we shall assume four experimentally observed points in the isothermal plane T', as follows:

$$A(h_A, p_A, v_A, T'); \qquad D(h_D, p_A, v_D, T');$$
$$B(h_B, p_B, v_B, T'); \qquad C(h_C, p_B, v_C, T'),$$

which are shown in Fig. 1. Points A and D are at the same pressure p_A;

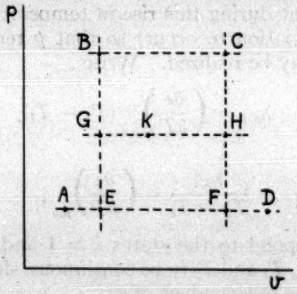

FIG. 1.

points B and C are at the same pressure p_B; and $p_A \neq p_B$. It should be noted that some of these points will necessarily be considered as metastable. With these four points, we shall find an expression for h as a function of (p, v), where $T = T'$, and the constants will involve the experimentally observed values of h, p, v for these four points.

If we select similar four experimentally observed points in the plane $T = T''$, we will have a second expression for h as a function of these new values of p, v. These two expressions will then be substituted in Eq. (16); we solve for $\nu(p, v)$ and $\psi(p, v)$ in terms of the observed values for all 8 points, and finally derive a general explicit expression for $h = f(p, v, T)$, where the constants may be calculated from the data of the 8 observed points.

Let us now proceed with the solution. Using the values for A and

D in (14) we have for line AD

$$h = h_A + (v - v_A)\frac{h_D - h_A}{v_D - v_A}. \tag{17}$$

On line AD, we can select two points, E (h_E, p_A, v_B, T') and F (h_F, p_A, v_C, T') where h_E and h_F can be calculated from (17). Using points B and E, we can with Eq. (15) calculate the equation for line BE; for any arbitrary point G (h_G, p_G, v_B, T') on this line, the total heat will be given by the equation

$$h_G = h_B + \frac{p_G - p_B}{p_B - p_A}\left[(h_B - h_A) - \frac{v_B - v_A}{v_D - v_A}(h_D - h_A)\right]. \tag{18}$$

Similarly, using points C and F, we can with Eq. (15) calculate the equation for line CF; for the point H (h_H, p_G, v_C, T') on this line, the total heat will be

$$h_H = h_C + \frac{p_G - p_B}{p_B - p_A}\left[(h_C - h_A) - \frac{v_C - v_A}{v_D - v_A}(h_D - h_A)\right]. \tag{19}$$

Using Eq. (14), together with (18) and (19), we may develop an equation for line GH. Realizing that p_G is any arbitrary pressure, write $p_G = p$. For any point K (h, p, v, T') on line GH, which is an arbitrary point in the isothermal plane $T = T'$, we have, on reducing terms,

$$\begin{aligned} h = {} & \frac{1}{p_B - p_A}\left[p_B\frac{h_A v_D - h_D v_A}{v_D - v_A} - p_A\frac{h_B v_C - h_C v_B}{v_C - v_B}\right] \\ & + v\cdot\frac{1}{p_B - p_A}\left[p_B\frac{h_D - h_A}{v_D - v_A} - p_A\frac{h_C - h_B}{v_C - v_B}\right] \\ & + p\cdot\frac{1}{p_B - p_A}\left[h_B - h_A + v_A\frac{h_D - h_A}{v_D - v_A} - v_B\frac{h_C - h_B}{v_C - v_B}\right] \\ & + pv\cdot\frac{1}{p_B - p_A}\left[\frac{h_C - h_B}{v_C - v_B} - \frac{h_D - h_A}{v_D - v_A}\right]. \end{aligned} \tag{20}$$

Write (20) in the form

$$h = Q_0 + Q_1 v + Q_2 p + Q_3 pv, \tag{21}$$

where the Q's may be calculated from the observations made on the four points A, B, C and D.

If a second set of 4 observed points are made in a second isothermal plane T'', we will have an equation similar to (21) to apply to this plane. Let us write then

$$h' = Q_0' + Q_1' v + Q_2' p + Q_3' pv, \tag{22}$$

$$h'' = Q_0'' + Q_1'' v + Q_2'' p + Q_3'' pv, \tag{23}$$

where the Q''s are determined from the observations in the first isothermal plane, and the Q'''s from the second isothermal plane. Substituting (22) and (23) in (16), solving for $\nu(p, v)$ and $\psi(p, v)$, we have on reducing terms

$$h = \left[Q_0' + \frac{T'}{T'' - T'}(Q_0'' - Q_0')\right] + v\cdot\left[Q_1' + \frac{T'}{T'' - T'}(Q_1'' - Q_1')\right] + p\cdot\left[Q_2' + \frac{T'}{T'' - T'}(Q_2'' - Q_2')\right] + pv\cdot\left[Q_3' + \frac{T'}{T'' - T'}(Q_3'' - Q_3')\right] - T\left[\frac{Q_0'' - Q_0'}{T'' - T'} + \frac{Q_1'' - Q_1'}{T'' - T'}v + \frac{Q_2'' - Q_2'}{T'' - T'}p + \frac{Q_3'' - Q_3'}{T'' - T'}pv\right]. \quad (24)$$

This can be written simply as

$$h = A + Bv + Cp + Dpv - T(E + Fv + Gp + Hpv), \quad (25)$$

where A, B, C, D, E, F, G and H are constants which can be determined from the eight sets of observations. This is the final equation of state which applies to a system which has a single type of transformation. It will be noted that this equation is general, in the sense that it includes all states, metastable as well as the stable states.

The latent heats may be calculated from (25), using Eqs. (11), (12) and (13). In the present paper we shall be interested only in $\lambda_{p,T}$, for that is the only latent heat for which we have experimental data. Thus

$$\lambda_{p,T} = (v_2 - v_1)\left(\frac{\partial h}{\partial v}\right)_{p,T} = (v_2 - v_1)[B - TF + p(D - TH)]. \quad (26)$$

3. EXPERIMENTAL VERIFICATION OF THE EQUATION OF STATE.

To verify Eq. (25) completely, we must have sets of experimentally observed values of h, λ, p, v, T over the entire region from $x = 0$ to $x = 1$. The writer has been unable to find such sets for the "metastable" states in the literature. The data are very meager, and what values do exist have been obtained partly by calculations on the basis of some equation involving but two independent variables.

However, Eq. (25) should also apply to the restricted set of "stable" states, for which we have sufficient data, and the writer has selected the data on ammonia and steam, substances which have been studied very extensively. For ammonia, the calculations are based on the tables

published by the National Bureau of Standards (2). For steam, the tables of both Keenan and Keyes (3) and those published by the National Bureau of Standards (4) were used. The writer compared these two tables over the entire range, and found them to be in agreement within practically their experimental error.

For each substance, the liquid and its saturated vapor was considered as one system; the superheated region was treated as a separate system. The calculations consisted in setting up a set of 8 simultaneous equations and solving for the constants. In the case of liquid ammonia and its saturated vapor, 19 points were taken along the saturated liquid line, and 19 along the saturated vapor line (indicated in Table I by stars in the first column), covering the entire range of the experimental data from $-60°$ F. to $+120°$ F., and from 5 to 290 lbs. per sq. in. The method of least squares was used to set up the set of 8 simultaneous

TABLE I.

Total Heat (h) and Latent Heat ($\lambda_{p,T}$) for Saturated Ammonia.

Point No.	t °F.	$T=t+459.58$	P lbs./in.²	v ft.³/lb.	h B.t.u./lb.		$\lambda_{P,T}$ B.t.u./lb.	
					Calculated	From Table	Calculated	From Table
(1)*	−60	399.58	5.55	0.02278	−21.83	−21.18	—	—
(1′)*	−60	399.58	5.55	44.73	586.6	589.6	610.4	610.4
(2)*	−50	409.58	7.67	.02299	−10.90	−10.61	—	—
(2′)*	−50	409.58	7.67	33.08	594.9	593.7	605.8	604.3
(3)	−45	414.58	8.95	.02310	−5.44	−5.31	—	—
(3′)	−45	414.58	8.95	28.62	596.6	595.6	602.1	600.9
(4)*	−40	419.58	10.41	.02322	0.00	0.00	—	—
(4′)*	−40	419.58	10.41	24.86	598.6	597.6	598.5	597.6
(5)*	−30	429.58	13.90	.02345	10.88	10.66	—	—
(5′)*	−30	429.58	13.90	18.97	601.5	601.4	590.7	590.7
(6)	−25	434.58	15.98	.02357	16.31	16.00	—	—
(6′)	−25	434.58	15.98	16.66	603.3	603.2	587.0	587.2
(7)*	−20	439.58	18.30	.02369	21.73	21.36	—	—
(7′)*	−20	439.58	18.30	14.68	604.9	605.0	583.6	583.6
(8)*	−10	449.58	23.74	.02393	32.55	32.11	—	—
(8′)*	−10	449.58	23.74	11.50	607.7	608.5	575.1	576.4
(9)	−5	454.58	26.92	.02406	37.96	37.51	—	—
(9′)	−5	454.58	26.92	10.23	609.7	610.1	571.8	572.6
(10)*	0	459.58	30.42	.02419	43.36	42.92	—	—
(10′)*	0	459.58	30.42	9.116	611.0	611.8	567.6	568.9
(11)*	10	469.58	38.51	.02446	54.16	53.79	—	—
(11′)*	10	469.58	38.51	7.304	614.2	614.9	560.1	561.1
(12)	15	474.58	43.14	.02460	59.57	59.24	—	—
(12′)	15	474.58	43.14	6.562	615.7	616.3	556.1	557.1
(13)*	20	479.58	48.21	.02474	64.98	64.71	—	—
(13′)*	20	479.58	48.21	5.910	617.4	617.8	552.4	553.1
(14)*	30	489.58	59.74	.02503	75.82	75.71	—	—
(14′)*	30	489.58	59.74	4.825	620.4	620.5	544.6	544.8
(15)	35	494.58	66.26	.02518	81.25	81.23	—	—
(15′)	35	494.58	66.26	4.373	621.8	621.7	540.6	540.5
(16)*	40	499.58	73.32	.02533	86.70	86.77	—	—
(16′)*	40	499.58	73.32	3.971	623.2	623.0	536.5	536.2
(17)*	50	509.58	89.19	.02564	97.67	97.93	—	—
(17′)*	50	509.58	89.19	3.294	625.8	625.2	528.1	527.3

TABLE I—*Continued.*

Point No.	t °F.	$T=t$ +459.58	P lbs./in.²	v ft.³/lb.	h B.t.u./lb.		$\lambda_{P,T}$ B.t.u./lb.	
					Calculated	From Table	Calculated	From Table
(18)	55	514.58	98.06	.02581	103.19	103.54	—	—
(18′)	55	514.58	98.06	3.008	627.0	626.3	523.7	522.8
(19)*	60	519.58	107.6	.02597	108.74	109.18	—	—
(19′)*	60	519.58	107.6	2.751	628.0	627.3	519.3	518.1
(20)*	70	529.58	128.8	.02632	119.97	120.54	—	—
(20′)*	70	529.58	128.8	2.312	629.8	629.1	509.9	508.6
(21)	75	534.58	140.5	.02650	125.6	126.25	—	—
(21′)	75	534.58	140.5	2.125	630.6	629.9	504.9	503.7
(22)*	80	539.58	153.0	.02668	131.38	131.99	—	—
(22′)*	80	539.58	153.0	1.955	631.2	630.7	499.7	498.7
(23)*	90	549.58	180.6	.02707	143.04	143.54	—	—
(23′)*	90	549.58	180.6	1.661	632.1	632.0	489.1	488.5
(24)	95	554.58	195.8	.02727	148.98	149.36	—	—
(24′)	95	554.58	195.8	1.534	632.6	632.6	483.7	483.2
(25)*	100	559.58	211.9	.02747	155.00	155.21	—	—
(25′)*	100	559.58	211.9	1.419	633.2	633.0	478.3	477.8
(26)*	110	569.58	247.0	.02790	167.32	167.01	—	—
(26′)*	110	569.58	247.0	1.217	633.4	633.7	466.0	466.7
(27)	115	574.58	266.2	.02813	173.64	172.97	—	—
(27′)	115	574.58	266.2	1.128	633.2	633.9	459.6	460.9
(28)*	120	579.58	286.4	.02836	180.08	178.98	—	—
(28′)*	120	579.58	286.4	1.047	633.0	634.0	453.1	455.0
(29)	135	594.58	354.1	.02911	200.22	(197.)	—	—
(29′)	135	594.58	354.1	—	—	—	—	—
(30)	175	634.58	593.5	.03160	262.19	(248.)	—	—
(30′)	175	634.58	593.5	—	—	—	—	—
(31)	210	669.58	888.1	.03482	453.48	(297.)	—	—
(31′)	210	669.58	888.1	—	—	—	—	—
(32)	270	729.58	1635.	.0577	531.58	(419.)	—	—
(32′)	270	729.58	1635.	—	—	—	—	—
(33) critical	271.4	730.98	1657.	.0686	556.05	(433.)	—	—

equations. The constants of Eq. (25) were found to be as follows:

$$A = -464.225 \qquad E = -1.108{,}38$$
$$B = -20.679 \qquad F = -0.057{,}610$$
$$C = -0.383{,}33 \qquad G = -0.000{,}596{,}93$$
$$D = +3.215{,}15 \qquad H = +0.002{,}945{,}1$$

Setting these constants in Eq. (25), the units will be as follows;* h in B.t.u. per pound; p in lbs. per sq. in.; v in cu. ft. per lb.; $T = t + 459.58$, where t is in °F.

The latent heats for ammonia were calculated from Eq. (26), using the above constants. All the results for saturated ammonia are given in Table I. In column (7), the values of h enclosed in parentheses were taken from the tables and represent values obtained by extrapolation beyond the range covered in the experimental work. It will be noted

* These are the units used in the ammonia tables; the zero point on the absolute temperature scale is the one used in these tables.

that the calculated values of h and $\lambda_{p,T}$ agree with those in the table over the entire range of the experimental observations to within a few tenths of a per cent., which is almost the accuracy of the experimental values.

In Table II are given the results of superheated ammonia. In this case only 8 points were selected (indicated by stars in the first column)

TABLE II.

Total Heat (h) for Superheated Ammonia.

Point No.	t °F.	$T=t+459.68$	p lb./in.²	v ft.³/lb.	h B.t.u./lb.	
					Calculated	From Table
(1)	−40	419.58	6	43.55	600.1	599.8
(2)*	0	459.58	6	47.90	620.1	620.1
(3)	60	519.58	6	54.32	650.3	650.3
(4)	−20	439.58	8	34.19	609.4	609.3
(5)	20	479.58	8	37.45	629.6	629.7
(6)*	60	519.58	8	40.68	649.9	649.9
(7)	120	579.58	8	45.48	680.6	680.5
(8)	160	619.58	8	48.66	701.4	701.3
(9)	−20	439.58	10	27.26	608.8	608.5
(10)*	20	479.58	10	29.90	629.1	629.1
(11)	80	539.58	10	33.78	659.7	659.7
(12)	120	579.58	10	36.35	680.3	680.3
(13)*	180	639.58	10	40.17	711.6	711.6
(14)	20	479.58	15	19.82	627.9	627.8
(15)	120	579.58	15	24.17	679.6	679.6
(16)	200	659.58	15	27.59	721.7	721.7
(17)	20	479.58	20	14.78	626.6	626.4
(18)*	60	519.58	20	16.12	647.5	647.5
(19)	100	559.58	20	17.43	668.4	668.5
(20)	160	619.58	20	19.37	700.0	700.0
(21)*	220	679.58	20	21.30	732.0	732.0
(22)	80	539.58	40	8.268	654.3	654.4
(23)*	160	619.58	40	9.609	697.7	697.7
(24)	260	719.58	40	11.24	752.6	752.3
(25)	120	579.58	100	3.454	667.0	667.3
(26)	240	699.58	100	4.294	737.6	736.5
(27)*	180	639.58	150	2.534	696.9	696.9
(28)	180	639.58	300	1.183	680.4	679.5
(29)	260	719.58	300	1.397	737.9	732.9

to form the set of simultaneous equations. The constants of Eq. (25) for this system were found to be as follows:

$$A = +410.112 \qquad E = -0.229{,}604$$
$$B = +0.016{,}619 \qquad F = +0.000{,}024{,}655$$
$$C = -0.323{,}570 \qquad G = -0.000{,}435{,}166$$
$$D = +0.312{,}046 \qquad H = -0.000{,}115{,}644$$

These constants require the same units as above for saturated ammonia. The agreement here between the calculated h and that derived from the table (except for point no. 29 for which no explanation can be offered)

is equal to the accuracy of the experimental values, i.e., about 0.1 per cent.

For saturated steam 19 points along the liquid line and 19 along the saturated vapor line were selected from Keenan's and Keyes' tables.

TABLE III.

Total Heat (h) and Latent Heat ($\lambda_{p,T}$) for Saturated Steam.

Data from Keenan's and Keyes' Tables.

Point No.	t °F.	$T = t + 459.69$	p lbs./in.²	v ft³./lb.	h B.t.u./lb.		$\lambda_{p,T}$ B.t.u./lb.	
					Calculated	From Table	Calculated	From Table
(1)	50	509.69	0.178,11	0.016,03	29.33	18.07	—	—
(1′)	50	509.69	0.178,11	1703.2	1077.5	1083.7	1048.2	1065.6
(2)	85	544.69	0.595,9	0.016,09	61.90	53.00	—	—
(2′)	85	544.69	0.595,9	543.5	1129.1	1098.8	1067.3	1045.8
(3)	120	579.69	1.692,4	0.016,20	94.49	87.92	—	—
(3′)	120	579.69	1.692,4	203.27	1102.9	1113.7	1008.4	1025.8
(4)	155	614.69	4.203	0.016,37	127.14	122.89	—	—
(4′)	155	614.69	4.203	86.52	1099.5	1128.1	972.4	1005.2
(5)	190	649.69	9.339	0.016,57	159.88	157.95	—	—
(5′)	190	649.69	9.339	40.96	1114.5	1142.0	954.6	984.1
(6)	224	683.69	18.557	0.016,80	191.85	192.17	—	—
(6′)	224	683.69	18.557	21.55	1137.1	1154.8	945.1	962.6
(7)	258	717.69	34.245	0.017,07	224.09	226.61	—	—
(7′)	258	717.69	34.245	12.144	1161.0	1166.7	936.9	940.1
(8)	292	751.69	59.356	0.017,37	256.73	261.36	—	—
(8′)	292	751.69	59.356	7.248	1183.0	1177.4	926.3	916.0
(9)	326	785.69	97.52	0.017,72	289.97	296.52	—	—
(9′)	326	785.69	97.52	4.538	1201.2	1186.7	911.3	890.2
(10)	360	819.69	153.04	0.018,11	324.05	332.18	—	—
(10′)	360	819.69	153.04	2.957	1214.5	1194.4	890.5	862.2
(11)	394	853.69	230.85	0.018,55	359.25	368.48	—	—
(11′)	394	853.69	230.85	1.992,0	1222.4	1200.2	863.2	831.7
(12)	430	889.69	343.72	0.019,10	398.17	407.79	—	—
(12′)	430	889.69	343.72	1.349,9	1224.3	1203.8	826.2	796.0
(13)	465	924.69	490.3	0.019,7	438.09	447.1	—	—
(13′)	465	924.69	490.3	0.946,3	1220.0	1204.5	781.9	757.4
(14)	500	959.69	680.8	0.020,4	480.65	487.8	—	—
(14′)	500	959.69	680.8	0.6749	1209.9	1201.7	734.2	713.9
(15)	535	994.69	923.2	0.021,3	526.63	530.3	—	—
(15′)	535	994.69	923.2	0.4868	1193.8	1194.6	667.2	664.3
(16)	570	1029.69	1226.5	0.0224	576.87	575.4	—	—
(16′)	570	1029.69	1226.5	0.3528	1172.0	1182.1	595.2	606.7
(17)	605	1064.69	1601.2	0.0239	632.82	624.3	—	—
(17′)	605	1064.69	1601.2	0.2545	1144.2	1162.0	511.4	537.7
(18)	640	1099.69	2059.7	0.0260	696.46	678.6	—	—
(18′)	640	1099.69	2059.7	0.1798	1108.8	1130.5	412.3	452.0
(19)	675	1134.69	2618.7	0.0297	773.06	745.4	—	—
(19′)	675	1134.69	2618.7	0.1196	1059.8	1078.0	286.8	332.6

The constants of Eq. (25) for this system were found to be as follows:

$$A = -444.76 \qquad E = -0.930,13$$
$$B = -3.803,59 \qquad F = -0.007,727$$
$$C = -0.046,03 \qquad G = -0.000,063,34$$
$$D = +3.907,2 \qquad H = +0.002,371,5$$

The units are in the British system as above. The absolute temperature scale is here defined by the equation $T = t + 459.69$. The results are shown in Table III. The agreement between the calculated values and those given in the table are not as good as for ammonia, differing by several per cent.

A second attempt was made for saturated steam, this time using only 8 points selected from the Bureau of Standards' table. In this case the

TABLE IV.

Total Heat (h) and Latent Heat ($\lambda_{P,T}$) for Saturated Steam.
Data from Bureau of Standard's Tables.

Point No.	t °C.	$T=t$ +273.16	p kgm./cm.²	v cm.³/g.	h IT cal./g.		$\lambda_{P,T}$ IT cal./g.	
					Calculated	From Table	Calculated	From Table
(1)	35	308.16	0.057,326	1.006,05	35.39	35.015	—	—
(1′)	35	308.16	0.057,326	25.245	—	—	—	—
(2)*	70	343.16	0.31775	1.0228	70.099	69.984	—	—
(2′)*	70	343.16	0.31775	5,045.3	627.30	627.3	557.2	557.3
(3)	105	378.16	1.2318	1.0474	105.04	105.14	—	—
(3′)	105	378.16	1.2318	1,419.4	668.40	641.0	563.4	535.8
(4)*	150	423.16	4.8535	1.0906	150.74	151.00	—	—
(4′)*	150	423.16	4.8535	392.57	655.99	656.0	505.2	505.0
(5)	175	448.16	9.1006	1.1208	176.78	177.01	—	—
(5′)	175	448.16	9.1006	216.60	658.59	662.4	481.8	485.4
(6)	200	473.16	15.857	1.156,5	203.49	203.59	—	—
(6′)	200	473.16	15.857	127.19	663.95	667.1	460.4	463.5
(7)*	230	503.16	28.531	1.2087	236.71	236.53	—	—
(7′)*	230	503.16	28.531	71.472	669.51	669.5	432.8	433.0
(8)	255	528.16	44.097	1.2631	265.60	265.19	—	—
(8′)	255	528.16	44.097	45.912	670.62	668.5	405.0	403.3
(9)	290	563.16	75.917	1.3655	308.53	308.10	—	—
(9′)	290	563.16	75.917	25.537	662.89	660.17	354.4	352.6
(10)*	310	583.16	100.64	1.4475	334.86	334.89	—	—
(10′)*	310	583.16	100.64	18.316	651.40	651.4	316.5	316.5
(11)	335	608.16	139.85	1.599	370.85	372.54	—	—
(11′)	335	608.16	139.85	11.841	626.25	631.8	255.7	259.3
(12)	367	640.16	207.11	2.083	431.66	440.45	—	—
(12′)	367	640.16	207.11	5.593	554.29	570.9	122.6	130.4
(13)	371	644.16	217.26	2.293	445.62	456.8	—	—
(13′)	371	644.16	217.26	4.681	532.52	550.5	86.9	93.7
(14) (critical)	374.15	647.31	225.65	3.1	481.24	498.	0	0

units are in the metric system, where t is in °C., $T = t + 273.16$, p in kgm. per sq. cm., v in cu. cm. per gram, and h and $\lambda_{p,T}$ in International calories per gram. The constants of Eq. (25) were found to be as follows:

$$A = -268.70 \qquad E = -0.986,85$$
$$B = -0.681,96 \qquad F = -0.002,080,5$$
$$C = +0.306,24 \qquad G = +0.000,509,75$$
$$D = +0.341,01 \qquad H = +0.000,274,07$$

In Table IV are shown the results based on these constants. It would

appear that no great advantage is obtained in using the 38 points in the former case, as compared to the use of only 8 points in this case. The agreement between the calculated and tabular values is of the same order of magnitude.

For superheated steam 8 points were selected from Keenan's and Keyes' tables to calculate the constants, indicated in Table V by stars

TABLE V.

Total Heat (h) for Superheated Steam.

Data from Keenan's and Keyes' Tables.

Point No.	t °F.	$T = t + 459.69$	p lbs./in.²	v ft.³/lb.	h B.t.u./lb.	
					Calculated	From Table
(1)	340	799.69	1	476.2	1044.2	1214.1
(2)*	200	659.69	2	196.06	1149.6	1150.0
(3)*	500	959.69	2	285.70	1288.8	1288.2
(4)	300	759.69	10	45.00	1254.2	1193.9
(5)	500	959.69	10	57.05	1319.5	1287.5
(6)	1000	1459.69	10	86.92	1601.4	1533.2
(7)*	400	859.69	30	16.897	1238.1	1237.9
(8)	700	1159.69	30	22.96	1390.3	1382.4
(9)*	800	1259.69	30	24.96	1428.0	1431.7
(10)*	1100	1559.69	30	30.94	1584.3	1584.5
(11)	500	959.69	60	9.403	1270.8	1283.0
(12)	850	1309.69	60	12.951	1444.7	1455.6
(13)	1000	1459.69	60	14.454	1500.6	1531.9
(14)	440	899.69	150	3.411	909.3	1242.0
(15)	750	1209.69	150	4.738	1448.7	1401.5
(16)	1100	1559.69	150	6.162	1493.8	1581.7
(17)*	600	1059.69	200	3.060	1323.6	1322.1
(18)*	950	1409.69	200	4.156	1504.3	1502.0
(19)	500	959.69	300	1.7675	775.7	1257.6
(20)	740	1199.69	300	2.314	1511.1	1389.3
(21)	1050	1509.69	300	2.962	1460.1	1551.6
(22)	600	1059.69	500	1.1591	1073.8	1298.6
(23)	800	1259.69	500	1.4405	1615.1	1412.1
(24)	950	1409.69	500	1.6358	1551.4	1492.8
(25)	1200	1659.69	500	1.9504	1260.0	1627.6
(26)	700	1159.69	1000	0.6084	1284.0	1325.3
(27)	900	1359.69	1000	0.7604	1693.9	1448.2
(28)	700	1159.69	2000	0.2489	1405.1	1240.0
(29)	1050	1509.69	2000	0.4126	1010.9	1505.7
(30)*	840	1299.69	2500	0.2473	1339.6	1339.9
(31)	750	1209.69	3000	0.1485	—	1197.8
(32)	1000	1459.69	3000	0.2476	1054.3	1441.8

in the first column. The constants were found to be as follows:

$$A = +1{,}927.37 \qquad E = +38.764{,}1$$
$$B = -3.159{,}08 \qquad F = -0.003{,}144{,}1$$
$$C = +15.428{,}0 \qquad G = +0.008{,}796{,}9$$
$$D = +63.044{,}6 \qquad H = -0.001{,}031{,}8$$

Comparing the calculated and tabular values for the total heat, as in-

dicated in Table V, one can say only that the agreement is fair compared to the results on superheated ammonia.

It is difficult to explain why the ammonia tables have shown such remarkable agreement, whereas the steam tables were only fair. At the present state of the development of the subject, one can only conjecture, and hope that additional experimental results may throw some light on this subject. As a tentative explanation, the writer would be inclined to examine the experimental and theoretical procedure in preparing the tables for ammonia and steam. The reader must bear in mind that Eq. (25) was derived on the basis that p, v, T are independent variables. This means that each quantity must be measured independently, and not calculated from the other two. It is the writer's impression that in the preparation of the ammonia tables fewer thermodynamic relations of the two-variable type were used than in the preparation of the steam tables. This may have some bearing on the lack of agreement between the calculated and tabulated values.

4. CONCLUSIONS.

The writer feels that nevertheless the agreement between the calculated and experimental values shown in the above tables is very encouraging support to the basic theme of the present and previous papers. The reader may argue that an equation of state which involves 8 constants ought to be capable of fitting almost any set of data. That would seem to be true ordinarily. However, we must bear in mind that Eq. (25) differs from other equations of state, first, in that it involves three, instead of two, independent variables. Second, it is an equation based on rational development, and is not a mere empirical form. Third, this equation includes the metastable states as well as the stable states. Fourth, by differentiating we obtain the latent heat; this could not usually be obtained from an empirical equation.

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(4) OSBORNE, N. S., STIMSON, H. F., AND GINNINGS, D. C.: "Thermal Properties of Saturated Water and Steam," Research Paper No. 1229, August 1939.

Tin in the Mexican Hills. (*Mining and Metallurgy*, Vol. 27, No. 479.)—When the seed is sown and the early summer rains set in, some thousands of Mexican farmers take to the hills in the search for tin. The 8,000–10,000 tons of tin they produce annually is sufficient to meet the needs of Mexico. No record of this production is available as only such tin as passes through the hands of the tax collector goes on record.

The mining in Mexico antedates the mining of silver for which Mexico is noted today as the world's largest producer. Cortez found tin coins in use when he first visited the Aztec capital. He described tin-lined copper pots made by the Indians, still produced unchanged in form and workmanship.

Unlike the production of other metals, tin is still being produced in an unorganized haphazard manner by antiquated methods. The Mexican *gambusino* mines only when and where he pleases. After the beans and corn are planted, he goes into the near-by hills. From narrow cracks in the rhyolite he gouges out soft exposures of ore. Sometimes he digs out the paystreak from the shallow sections of the placers. He hand-grinds the ore on a flat rock and washes it, finishing his concentrating process with a wooden batea, but his recovery by this crude method compares favorably with that of many mills.

After accumulating sufficient concentrate he packs it down to the nearest town where he makes a trade with the local storekeeper. These storekeepers are often ore buyers for one of the ten to twelve custom tin smelters in the country. With old-fashioned equipment these custom smelters manage to smelt the tin which is later used in dishes, trays, picture frames, images, and ornaments. Some of the tin finds its way into the fabrication of bronze church bells, pewter candlesticks, solder, and babbitt.

It is noteworthy that this crude method of production has persisted for centuries. Areas in which tin is found are pock-marked with ancient workings. The *gambusino* merely looks for one of these holes and starts picking out the ore.

Cassiterite occurs in countless narrow shrinkage cracks formed in the cooling-off period of the rock mass. These cracks carry deposits of soft high-grade tin ore, mixed with iron oxides and frequent clusters of clean nodules of cassiterite.

Cassiterite is also found in hard and medium-hard masses of rhyolite in addition to the more frequently worked deposits in the softer rocks. The occurrences of tin ore are known in at least ten of Mexico's states over an area of 25,000 square miles.

No definite pattern for the deposits has ever been determined. There is no regularity of the grouping of the mineral in the host rock nor in the size of the spots and streaks. The deposits vary in size from the more commonly found specks to the occasional deposits of a ton or more of clean ore. The *gambusino* never turns his hand at dead work. Once one streak runs out he always turns to another showing on the surface. Such an irregular deposit does not permit the application of the customary methods of sampling. The determination of the average content and value of these deposits awaits the man who can devise a plan of accurate sampling.

R. H. OPPERMANN.

A DYNAMICAL ANALOGUE

BY

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1. INTRODUCTION.

This paper outlines certain possibilities for a graphical integration of ordinary differential equations by means of a dynamical analogues of a pendulum type.

The question of mechanical integration is not new. It is sufficient to mention that Leibnitz [1] * and, later on, the physicists of the nineteenth century, particularly Lord Kelvin [2], considered the possibility of facilitating the work of numerical computations frequently long and tedious, particularly when the solutions are given in the form of infinite series. These early developments did not result, however, in any practical developments, very likely on account of a not sufficiently advanced state of mechanical art, lack of proper tools and materials, etc.

The modern developments of computing machines began with the differential analyzer of Dr. V. Bush [3]. This machine still occupies a dominating position in this new field. A number of other developments appeared recently, evidencing a growing interest in this problem.

In the Bush machine the various terms of a differential equation are represented by angular motions of certain shafts; these motions are combined into a resultant motion which thus appears as a *kinematical image* of the differential equation in question. In order to obtain this kinematical process a number of basic mechanical units, such as integrators, multipliers, adders, etc, is employed. The higher the order of the differential equation, the greater is the number of these units. The principal merit of the machine is the great variety of differential equations which it can handle as well as the accuracy with which the solutions are obtained.

In addition to this machine, there appeared also the so-called computing machines carrying out automatically a sequence of arithmetical operations according to some method of numerical integration.

Quite independently of the development of the machines, there appeared also an entirely different line of approach to the same problem in the form of the so-called *analogues*.

The underlying idea of an analogue can be specified as follows: Suppose that we are interested in a certain phenomenon A whose study either theoretical, or experimental or, possibly, both, presents some difficulties. It is known, however, that there exists another phenome-

* Numbers in heavy parenthese indicate references on page 149.

non B governed by the same differential equation as A but which is more accessible to experimental determination. In such a case B will be used as an analogue of A and all conclusions obtained with B will be applicable to A in view of the identity of the differential equations in both cases.

As an example consider the problem of the determination of the field of electric intensity produced by a certain configuration of charged bodies in air. If this configuration is somewhat complicated, the theoretical approach may be very difficult. On the other hand, the experimental determination of the potential of different points of the field in air is not easy too. Analytically the problem is governed by the Laplace-Poisson equation. The same equation governs also the distribution of electric current in an electrolytic tank. Since the experimental determination of the streamlines of electric current in such a tank is a much simpler proposition, the electrolytic tank will be taken as the analogue of the corresponding electric field. In this particular case one physical phenomenon is taken as the analogue of another one. There may be, however, a somewhat different viewpoint on this situation. In fact, we may just as well consider an electrolytic tank as an analogue of the Laplace-Poisson equation. This last mentioned point of view will be particularly useful in what follows.

The differential equation of a damped physical pendulum is

$$A\ddot{\theta} + B\dot{\theta} + C\theta = 0, \tag{1}$$

where A, B and C are well-known physical constants and θ is the angle of oscillation, supposed to be small so that $\operatorname{Sin}\theta \cong \theta$ within a certain degree of approximation. In line with the point of view just mentioned we can also say that a damped pendulum *represents* a differential equation of the second order with constant coefficients or, which is the same, *is an analogue* of such an equation. This brings us directly in contact with our problem.

2. THE PENDULUM AS A DYNAMICAL ANALOGUE.

It is apparent that, if instead of an ordinary pendulum one has a dynamical system with one degree of freedom whose differential equation is

$$f_2\ddot{\theta} + f_1\dot{\theta} + f_0\theta = 0, \tag{2}$$

where f_1, f_0 and f_2 are certain functions either of the independent variable t or of the dependent variable θ or, possibly, of both, the motion of such a system, which we may still call a "pendulum," if properly recorded on a moving chart (θ, t), will give the integral curve of (2). We may also say that such a pendulum will "integrate" the differential equation (2).

We shall exclude the case when $f_2 = 0$, in which case the differential equation of the second order *degenerates* into the one of the first order. One can, therefore, divide (2) by f_2 and setting $f_0/f_2 = F_0$, $f_1/f_2 = F_1$,

we write it as

$$\ddot{\theta} + F_1\dot{\theta} + F_0\theta = 0. \tag{3}$$

This equation may, obviously, be considered as a "pendulum" with a unit moment of inertia (in a certain scale) whose coefficients of damping and "pendulousness" (or "spring constant") are functions of some variables. A few examples will illustrate this thought.

Let us assume that $F_1 = 0$ and $F_0 \neq 0$.

(a) $F_0 = F_0(t) = a^2 + b^2 \operatorname{Cos} t$. In this case we have the Mathieu equation

$$\ddot{\theta} + (a^2 + b^2 \operatorname{Cos} t)\theta = 0. \tag{4}$$

(b) $F_0 = F_0(t) = a_0 + \sum_1^n [a_n \operatorname{Cos} nt + b_n \operatorname{Sin} nt]$. This gives the Hill equation

$$\ddot{\theta} + (a_0 + \sum_1^n [a_n \operatorname{Cos} nt + b_n \operatorname{Sin} nt])\theta = 0. \tag{5}$$

These equations are obtained if the pendulousness of the pendulum is made to vary periodically.

(c) $F_0 = F_0(t) = p(t) + \lambda q(t)$, where p and q are some continuous bounded functions in a certain interval and λ is a parameter. This gives the differential equation

$$\ddot{\theta} + (p(t) + \lambda q(t))\theta = 0. \tag{6}$$

This equation is encountered in connection with boundary value problems [4]. One recognizes this easily by replacing θ by y and t by x. A particular case of this equation is the unidimensional Schrodinger equation

$$\ddot{\theta} + (W - V(t))\theta = 0. \tag{7}$$

One ascertains this by replacing θ by ψ, the wave function, and t by x, in which case $V(x)$ is the potential energy and W is the total energy of the particle.

(d) $F_0 = F_0(\theta)$ results in a non-linear differential equation of the form

$$\ddot{\theta} + F_0(\theta)\dot{\theta} = \ddot{\theta} + \psi(\theta) = 0. \tag{8}$$

This is a differential equation of the non-linear conservative system.

$$\text{(e)} \quad F_0 = F_0(t, \theta) = (a^2 + b^2 \operatorname{Cos} t)\psi(\theta). \tag{9}$$

This leads to a non-linear Mathieu equation

$$\ddot{\theta} + (a^2 + b^2 \operatorname{Cos} t)\psi(\theta) = 0. \tag{9}$$

(f) $F_0 = 1$; $F_1 = -\mu(a^2 - g(\theta))\dot{\theta}$, where a^2 is a constant, μ is a parameter and $g(\theta)$ is an even monotone increasing function such that

$g(0) = 0$. This gives the Van der Pol equation

$$\ddot{\theta} - \mu(a^2 - g(\theta))\dot{\theta} + \theta = 0. \tag{10}$$

These few examples show a great variety of differential equations which can be "represented" by a generalized pendulum analogue of this kind. In fact most any differential equation of the second order can be interpreted on this basis. Incidentally, equation (9) remains entirely unexplored at present although it is suspected to govern a special type of a non-linear oscillation as will be mentioned later.

Even among the differential equations of known types not all have been explored analytically so far. Thus, for example, the Mathieu equation has been investigated only as far as its periodic solutions are concerned in which case these solutions are expressed in terms of the so-called Mathieu functions. Still less explored are the non-linear differential equations; their solutions can be determined only when the non-linearity is relatively small, when, consequently, the non-linear equation remains in the neighborhood of the corresponding linear one.

Still less studied are some of these equations in the case of an external periodic excitation in which case there appears the so-called forcing function $f(t)$ on the right hand side of the equation. Some of these equations will be mentioned later in connection with recently investigated problems of non-linear mechanics. The experimental study of these phenomena is generally conducted in connection with electron tube circuits. Considered as a non-linear conductor, an electron tube is not a very convenient one. In fact, the nature of its non-linearity changes from point to point of its characteristic. It is impossible to change the nature of the non-linearity in a given electron tube. For these reasons a considerable advantage could be gained if these experimental studies were conducted with the characteristics of definite forms, e.g., quadratic, cubic, square root, etc. It will be shown that with an arrangement outlined below this can be accomplished in a relatively simple manner.

3. ELECTRODYNAMOMETER AS A GENERALIZED PENDULUM.

We propose now to show that a moving element formed by the coil of an ordinary electrodynamometer offers an interesting possibility for obtaining a generalized pendulum needed for the problem outlined in the preceding section. Consider (Fig. 1) a circular coil C capable of rotating (we assume a negligible friction) over a small angle about its diameter inside a solenoid S producing a uniform magnetic field H. From the theory of the electrodynamometer it follows that the couple M acting on the movable system is of the form

$$M = \lambda i_1 i_2 \operatorname{Sin} \theta \cong \lambda i_1 i_2 \theta, \tag{11}$$

where i_1 and i_2 are the currents in the solenoid and in the coil respectively and λ is a physical constant depending on geometry, number of turns,

etc. It is well known that, designating by θ the angle between the magneto-motive force j (Fig. 2) of C and the field H, the stable equilibrium of C occurs for $\theta = 0$; for $\theta = \pi$ the equilibrium is unstable. For the stable equilibrium the currents i_1 and i_2 are parallel as shown in Fig. 1.

Considering the quantity $(\lambda i_1 i_2)$ as the "pendulousness" of the pendulum formed by C with the associated attachments, the angular

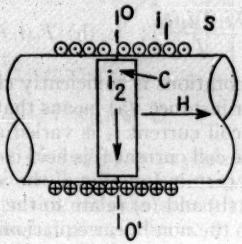


FIG. 1.

motion of the system for small angles θ is given by the differential equation

$$I\ddot{\theta} + (\lambda i_1 i_2)\theta = I\ddot{\theta} + k^2\theta = 0. \qquad (12)$$

If both currents are fixed, that is $i_1 = i_{10}$; $i_2 = i_{20}$, k^2 is a constant and (12) represents an ordinary harmonic oscillator with frequency $\omega = \sqrt{k^2/I}$. In the neighborhood of $\theta = \pi$, sign minus must be taken in equation (12) and the motion is then unstable. If one limits the

FIG. 2.

maximum excursion of the movable system to, say, 20° the approximation (Sin $\theta \cong \theta$) is within less than 1 per cent. If a still greater accuracy is desired the range of the instrument must be limited to still smaller angles.

From the form of the quantity $F_0 = \dfrac{\lambda i_1 i_2}{I}$ one observes that there is a great variety of different combinations available with this arrangement for the purpose of producing any desired F_0. Designating by the sub-

script 0 the current which is held constant we have the following combinations:

(a) $F_0(t) = \frac{\lambda i_{10} i_2(t)}{I}$; (b) $F_0(t) = \frac{\lambda i_{20} i_1(t)}{I}$; (c) $F_0(t) = \frac{\lambda i_1(t) i_2(t)}{I}$;

(d) $F_0(\theta) = \frac{\lambda i_{10} i_2(\theta)}{I}$; (e) $F_0(\theta) = \frac{\lambda i_{20} i_1(\theta)}{I}$; (f) $F_0(\theta) = \frac{\lambda i_1(\theta) i_2(\theta)}{I}$;

(g) $F_0(t, \theta) = \frac{\lambda i_1(t) i_2(\theta)}{I}$; (h) $F_0(t, \theta) = \frac{\lambda i_1(\theta) i_2(t)}{I}$.

The meaning of these notations is sufficiently clear from the preceding conventions. Thus, for instance, (a) means that the solenoid current is held constant and the coil current i_2 is varied as a certain function of time; (e) means that the coil current i_2 is held constant and the solenoid current i_1 is varied as a certain function of the angle θ and so on. It is clear that the cases (a), (b) and (c) relate to the linear differential equations, (d), (e) and (f) to the non-linear equations and (g) and (h) to the mixed types as was explained in connection with equation (9). It is also apparent that the cases (a) and (b) are equivalent since it is immaterial whether i_1 is held constant and i_2 is varied or vice versa since the moment M is expressed by the product $i_1 i_2$. Likewise the pairs (d), (e), (g), and (h) are also equivalent.

4. INTRODUCTION OF FUNCTIONS INTO THE ANALOGUE.

In all devices for mechanical integration it is necessary to supply the machine with "analytical information" using the term of D. R. Hartree [5]. Thus, for example, in the differential analyzer this analytical information is supplied by the operator controlling the operation of the machine by following the graph of a certain function on the input table. In this case the analytical information must appear as a certain prescribed law of variation of i_1 or of i_2 or both. For the linear differential equations the currents must be varied as certain explicit functions of time. For the non-linear equations their variation must occur as a function of θ. This requires a different arrangement as will be later explained.

In earlier publications on this subject [6] the application of the so-called *integrating contour* was described. As the recent developments in the so-called *photo-integraphs* [7] seem to offer a more practical solution of this problem, it was thought that a review of this subject with this new method of introducing the prescribed functions into the analogue is worth while.

It is useful to recall briefly the principle of the photo-integraph. A luminous flux of a constant intensity per unit area but of a variable cross-section enters inside a sphere whose interior surface is coated with a light diffusing substance. Owing to the multiple reflections of light

inside the sphere, the average intensity of illumination not in a direct path of the luminous beam is found to be proportional to the luminous flux and, hence, to the area through which it penetrates into the sphere. Thus, for example, if a shutter K, shown in Fig. 3, provided with an

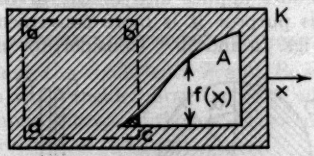


Figure 3

aperture A limited by a curve $f(x)$ is moved across a light-conveying channel *abcd* with a uniform luminous intensity at a constant speed v_0, the luminous flux penetrating into the sphere at any instant is proportional to the doubly shaded area, that is, to the quantity $\int_0^x f(x)dx$. The response of the photo-electric cell and, therefore, the current which it controls (assuming linearity in the amplifying system) will be also of the form $\phi(x) = \int_0^x f(x)dx$. The method applies only to the monotone increasing functions $\phi(x)$. In case the function has maxima or minima, an artificial means employing areas with "negative light" is generally used [8]. In what follows we shall not need this complication and will describe a few typical examples of the application of the photo-integraph to the problems just mentioned.

5. DIFFERENTIAL EQUATIONS WITH PERIODIC COEFFICIENTS.

Assume first a simple case (Fig. 4) of a shutter K provided with a rectangular aperture A oscillated sinusoidally across a light conveying channel *abcd* so as to vary the luminous flux penetrating into the photo-

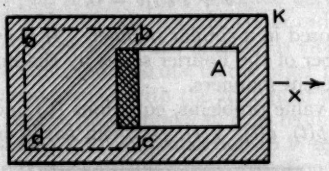
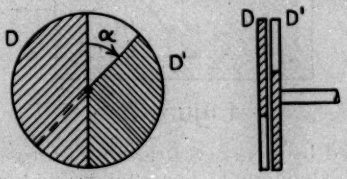


Figure 4

integraph. Let Δi_2 be the amplitude of the coil current variation in response to the oscillation of the luminous flux so produced and i_{20} the average current around which these oscillations occur. It is clear that the quantity $(i_{20} + \Delta i_2 \operatorname{Cos} t)$ will give rise in the equation (12) of the analogue to the term $(a^2 + b^2 \operatorname{Cos} t)$ of the Mathieu equation. By

changing the parameters i_{20} and Δi_2 one can thus explore the whole field of solutions of the Mathieu equation, establish the thresholds between the stable and the unstable solutions, ascertain the effect of the frequency of the ripple, etc.

A similar procedure applies also to the investigation of the Hill equation. For this purpose it is more convenient to use a rotating shutter shown in Figs. 5a and 5b. Consider, for instance, a stationary



5a 5b

Figure 5

disc D half opaque and half transparent and a similar disc D_1 rotating in front of it. In this case the light conveying area changes linearly with angle α and gives rise to a variable luminous flux represented in Fig. 6. The periodic function $F_0(t)$ so obtained in conjunction with the

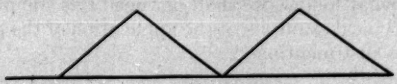


Figure 6

analogue will give rise to the Hill equation

$$\ddot{\theta} + F_0(t)\theta = 0, \tag{13}$$

which can be explored in a similar manner. It is evident that one can produce any number of the Fourier series by shaping the opaque areas on the disc in different manners.

For boundary value problems, equations (6) and (7), the introduction of functions $p(t)$, $q(t)$, $V(t)$, etc., can easily be obtained by this

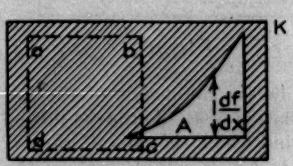


Figure 7

method. It is sufficient to recall that if a function, say, $f(x)$, is to be introduced into the analogue, the shutter K (Fig. 7) is to be limited by the function df/dx. If the shutter is moved across the light conveying channel *abcd* at a constant speed v_0, it is apparent that the function $f(t)$ will be introduced into the analogue.

6. NON-LINEAR DIFFERENTIAL EQUATIONS.

For these equations the coefficients F and F_0 in equation (3) are functions of θ. We will consider first the case when $F_1 = 0$. This corresponds to the important case of the non-linear conservative systems with one degree of freedom of the general form

$$\ddot{\theta} + \psi(\theta) = \ddot{\theta} + F_0(\theta)\theta = 0. \tag{14}$$

It is obvious that in this case the shutter must be fixed to the oscillating system. As an example, let us consider a simple case, $\psi(\theta) = \kappa^2\theta^2$; $F_0(\theta) = k^2\theta$. The relative position of the shutter K and the light conveying channel *abcd* developed on a plane is shown in Fig. 8. The

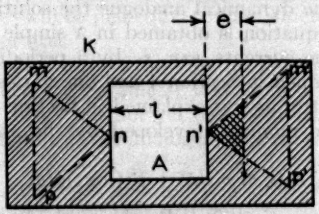


Figure 8

aperture A is rectangular of the width 1. Two triangular channels *mnp* and *m'n'p'* are associated with two photo-integraphs for the purpose of obtaining a push pull action. The distance between the points n and n' must be preferably slightly less than 1 in order to avoid "dead zones" around $\theta = 0$. For $\theta = 0$ the channel is closed; for $\theta \neq 0$ the luminous flux will be admitted into one or the other photo-integraph as indicated by the shaded area. With the triangular apertures *mnp* and *m'n'p'* the response will be proportional to θ^2 as required. The electrodynamic couple will also vary in proportion to θ^2 so that under these circumstances the analogue will "integrate" equation (14) which, in this case, should be written as

$$\ddot{\theta} + k^2|\theta|\theta = 0, \tag{15}$$

since the motion should be symmetrical with respect to $\theta = 0$. If, instead of triangular apertures *mnp*, *m'n'p'*, these apertures were limited by parabolic curves, the analogue would integrate the equation

$$\ddot{\theta} + k^2\theta^3 = 0.$$

It is apparent that the method is quite general and by shaping the apertures properly a great variety of equations of this type can be integrated by recording the oscillation on a moving chart.

7. DIFFERENTIAL EQUATIONS INVOLVING FUNCTION $F_0(t, \theta)$.

These equations have not been studied so far. Equation (9) is an equation of this kind. In this connection it is interesting to note that L. Mandelstam and N. Papalexi in their studies of the so-called parametric excitation [9] were led to investigate the unstable solutions of the Mathieu equation in order to explain the performance of their "hetero-parametric generator." In carrying out this work they found that the generator built in accordance with the linear Mathieu equation runs up to such a high voltage that the insulation is punctured very rapidly. In order to avoid this they introduced a non-linear element and obtained a stable performance. Unfortunately it was impossible to give a theory of the machine under these conditions inasmuch as there exists no theory of non-linear equations with periodic coefficients.

In the case of the dynamical analogue the solution of a non-linear Mathieu (or Hill) equation is obtained in a simple manner, viz.: one modulates one of the currents, say, i_1, by a periodic operation of the shutter as was explained in Section 4 and one varies the other current i_2 by a movable shutter as was explained in Section 6 so as to produce the term $\psi(\theta)$. The moment developed by the analogue gives then the term

$$F_0(t, \theta) = (a^2 + b^2 \operatorname{Cos} t)\psi(\theta)$$

in conformity with equation (9). By the method explained in connection with Fig. 5, the analogue will integrate also a non-linear Hill equation of the form

$$\ddot{\theta} + F(t)\psi(\theta) = 0, \tag{16}$$

where $F(t)$ is a periodic function of t and $\psi(\theta)$ is a non-linear function of θ.

8. DIFFERENTIAL EQUATIONS OF THE VAN DER POL TYPE.

The differential equation of self-excited non-linear oscillations discovered by Van der Pol is one of the outstanding discoveries of the last two decades and gave, more than anything else, a stimulus to modern studies in non-linear mechanics. It covers an enormous and yet little explored field of self-excited oscillations both electrical and mechanical.

The original equation as formulated by Van der Pol himself is

$$\ddot{x} - \mu(1 - x^2)\dot{x} + x = 0. \tag{17}$$

Later authors specified more general forms of the Van der Pol equation. Liénard [10] indicated the form of this equation

$$\ddot{x} + f(x)\dot{x} + g(x) = 0, \tag{18}$$

which is also of a Van der Pol type provided f is a certain even function and g is an odd differentiable function.

N. Levinson and O. K. Smith [11] indicated a stil lmore general form of this equation

$$\ddot{x} + f(x, \dot{x})\dot{x} + g(x) = 0 \tag{19}$$

and showed that this equation may exhibit solutions of the Van der Pol type provided the functions f and g satisfy certain conditions.

Considered from the standpoint of the analogue, the Van der Pol equation

$$\ddot{\theta} - \mu(1 - \theta^2)\dot{\theta} + \theta = 0 \tag{20}$$

is a certain pendulum possessing a peculiar damping. For small angles the damping is negative, which means that energy is *absorbed*. For larger angles the damping becomes of an ordinary dissipative type. The equilibrium point $\theta = 0$ is, therefore, unstable. A pendulum of this kind will start from rest at $\theta = 0$ and will reach a certain stationary state of oscillation at which the energy absorbed during its passage through small angles will be just equal to that which is dissipated during the motion on larger arcs.

The mathematical theory of the Van der Pol equation is sufficiently well established when the parameter μ is small. For larger values of the parameter the theory has not yet been completed.

From the standpoint of the analogue, this equation is characterized by the values $F_0 = 1$; $F_1 = -\mu(a^2 - b^2 f(\theta))$ in equation (3), where a^2 and b^2 are certain constants and $f(\theta)$ is a continuous even monotone increasing function of θ, such that $f(0) = 0$.

It is seen that the whole problem of producing a Van der Pol pendulum centers on the production of the damping term in the analogue. Disregarding momentarily the parameter μ which merely specifies the relative importance of the damping term as compared to the other two terms, it is observed that the production of this damping term in the analogue can be made if one of the currents, say, i_1, is made to vary in proportion to $\dot{\theta}$ and the other one i_2 in proportion to the function

$$a^2 - b^2 f(\theta).$$

There are several ways of obtaining a current varying in proportion to $\dot{\theta}$. One of the simplest consists in attaching to the axis of oscillation O, Fig. 9, a pair of flat modulating coils c_1 and c_2 moving in the air gap of an a.c. magnet m whose pole face is shown in broken line. The voltages induced in the coils are thus amplitude modulated voltages varying in proportion to θ. By filtering out the carrier and differentiating the demodulated signal, one obtains finally in the push-pull circuit the response proportional to $\dot{\theta}$ which in this case will result in a magnetic field of the solenoid oscillating in phase with $\dot{\theta}$.

As regards the second term $a^2 - b^2 f(\theta)$ to be produced, it is apparent that an arrangement involving two coils on the moving element will solve the problem as follows: one of these coils will carry a constant current representing a^2 and the other one will carry a variable current

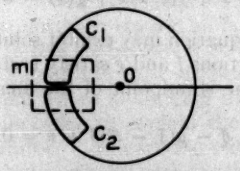


Figure 9

representing the term $-b^2 f(\theta)$ counteracting the action of the first one. The control of this second term is shown in Fig. 10. A shutter K attached to the movable system has the form shown. For $\theta = 0$ the shutter just closes the light conveying channel *abcd*. For $\theta \neq 0$ the luminous flux penetrating into the photo-integraph will increase in proportion to θ^2 resulting from the fact that the shutter is limited by the triangles P and Q.

Finally, in order to take into account the minus sign in equation (20) the connections must be made so that for the excitation a^2 alone the

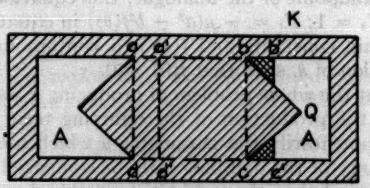


Figure 10

position of equilibrium $\theta = 0$ be unstable. If one desires to vary the parameter μ in the equation it is sufficient both excitations a^2 and b^2 *in the same direction* which will change the value of the damping term with respect to the two other terms in equation (20).

By varying the form of the controlling shutters P and Q, the Van der Pol equation can be explored for different forms of the functions $f(\theta)$. Thus, for instance, if the shutters are limited by the parabolic arcs, the analogue will "integrate" the equation

$$\ddot{\theta} - \mu(a^2 - b^2|\theta|^3)\dot{\theta} + \theta = 0.$$

This is also a Van der Pol equation in which the cubic function is written as it is instead of θ^3 in order to preserve the even character of

the function as required by the symmetry of oscillations. It is apparent that this condition is automatically fulfilled with the arrangement shown.

9. BOUNDARY VALUE PROBLEMS; EIGEN-VALUES AND EIGEN-FUNCTIONS.

In boundary value problems one encounters frequently a differential equation of the form

$$\frac{d^2y}{dx^2} + [q(x) + \lambda p(x)]y = 0, \tag{21}$$

where p and q are continuous and bounded in a certain interval (a, b) and λ is a parameter. It is shown that for a certain discrete set of values $\lambda_1, \lambda_2, \ldots$, the solutions, satisfy the first boundary condition $y(a) = y(b) = 0$. For the analogue this equations is

$$\ddot{\theta} + [q(t) + \lambda p(t)]\theta = 0. \tag{22}$$

It is seen that this problem may be considered as a record of a pendulum with $F_0 = q(t) + \lambda p(t)$. Since this problem involves the sum of the two functions, two analogues rigidly connected to each other as shown in Fig. 11 are required. Assume that the two coil currents i_2

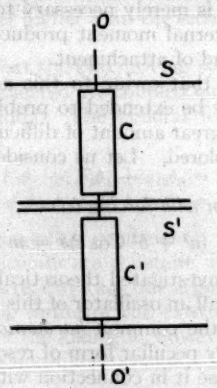


Figure 11

and i_2' are held fixed and two solenoid currents i_1 and i_1' are varied by two photo-integraphs controlled by shutters so as to introduce the functions q and p in the manner previously explained in connection with Fig. 7. The motion of the movable system will then take place in accordance with equation (22). Here we encounter, however, a peculiar situation. Assume that we start the record when $\theta = 0$ at the point $x = a$ of the record. It is by no means certain that the solution will pass through zero at the other end $x = b$ of the interval. The parameter

λ (here i_2 or i_2') is then adjusted and the observation repeated until the solution will ultimately pass through zero for $x = b$, assuming that each time we start from the same initial condition: $\theta = 0$ for $x = a$. When this is reached the value of the parameter λ_1 is then the *first eigen-value* and the function $\theta_1(x)$ traced by the analogue is the *first eigen-function* of the problem.

One can easily apply this method for instance to the problem of a vibrating string with a non-uniform density or to the unidimensional Schrödinger equation (7).

When the functions q and p are relatively simple the advantage of the analogue may not be great since in such cases the analytic solutions are generally available. The real advantage of the analogue may occur in connection with complicated forms of these functions when the analytic solutions are either extremely difficult or entirely unknown.

10. NON-HOMOGENEOUS DIFFERENTIAL EQUATIONS.

We consider now the cases when equation (3) has on its right-hand side the so-called *forcing function* $f(t)$ which we will assume to be periodic. From the standpoint of the analogue this does not constitute any difficulty at all; it is merely necessary to apply to the axis of the movable system an external moment produced either mechanically or electrically by some kind of attachment.

It is easy to show that owing to this additional attachment the analogue solutions may be extended to problems which have been investigated only with a great amount of difficulties; some of these problems remain still unexplored. Let us consider a few typical problems of this kind.

(a) *Mathieu equation with forcing term.*

$$\ddot{\theta} + (a^2 + b^2 \operatorname{Cos} t)\theta = m \operatorname{Sin} \omega t. \tag{23}$$

This problem was investigated theoretically by Gorelik and others [12]. These authors call an oscillator of this kind the *periodic* oscillator to distinguish it from the common *harmonic oscillator*. The periodic oscillator exhibits a very peculiar form of resonance which led Mandelstam and Papalexi to use it in connection with the development of the so-called autoparametric filter [13]. This study is yet in an early stage.

(b) *Non-linear differential equations with forcing term.*

There exists a considerable literature on this subject particularly in connection with the so-called Duffing equation [14]

$$\ddot{\theta} + \alpha\theta - \beta\theta^2 - \gamma\theta^3 = k \operatorname{Sin} \omega t. \tag{24}$$

Here again the analogue may be helpful in extending the studies through all possible values of the parameters and functions $\psi(\theta)$.

(c) *Equations of the Van der Pol with forcing term.*

$$\ddot{\theta} - \mu(a^2 - b^2 g(\theta))\dot{\theta} + \theta = f(t), \tag{25}$$

where $f(t)$ is a periodic function. This equation has been partially investigated and a number of interesting conclusions was reported. It is observed, for instance, that under certain conditions the external, or hetero-parametric, frequency may cause the appearance of the self-excited, or auto-parametric, frequency; under some other conditions, on the contrary, the hetero-parametric frequency may extinguish the existing auto-parametric frequency [15]. These phenomena are designated sometime as *asynchronous excitation or quenching;* they depend apparently on the *form* of the non-linearity. Most of the experiments on this subject were made by means of electron tube circuits but, as was previously mentioned an electron tube, considered as a non-linear conductor, is a not very convenient one. A dynamical analogue of this type may offer a more practical means for studying these complicated problems owing to the facility with which the various functions can be introduced into the problem.

11. DIFFERENTIAL EQUATIONS OF HIGHER ORDERS

By coupling several analogues together, it is also possible to integrate the systems of differential equations, or, which is the same, the differential equations of the order higher than the second with which we were concerned so far.

Assume, for example, that the two moving systems shown in Fig. 11 instead of being rigidly connected are coupled mechanically together by means of an elastic coupling. The general form of the differential equations in such a case is:

$$\begin{aligned} \ddot{\theta}_1 + F_1\dot{\theta}_1 + F_0\theta_1 + c_{12}\theta_2 &= 0, \\ \ddot{\theta}_2 + \phi_1\dot{\theta}_2 + \phi_0\theta_2 + c_{21}\theta_1 &= 0, \end{aligned} \tag{26}$$

where c_{12} and c_{21} are the coupling coefficients. If one leaves out the trivial case when all coefficients are constant, which leads to the well known linear case, one sees readily that one is generally confronted with problems which exceed the limits of the existing analytical methods. No such difficulties exist for the analogue, however. As an example, let us take a relatively simple non-linear system,

$$\begin{aligned} \ddot{\theta}_1 + \alpha_1(\theta_1) + c_{12}\theta_2 &= 0, \\ \ddot{\theta}_2 + \alpha_2(\theta_2) + c_{21}\theta_1 &= 0, \end{aligned} \tag{27}$$

representing two non-linear conservative dynamical systems coupled together. The analytical procedure in this case is sufficiently complicated and is limited only to a relatively narrow case when each of the component systems is of a quasi-linear case, that is, not far from the linear one.

Still more difficult is the case when the functions F_1 and ϕ_1 in equations (26) are of the Van der Pol type. This case arises, for example, when two self-excited generators are coupled together. Although,

under the assumption of a quasi-linearity, the method of Poincaré can still be applied to this case [16], the procedure becomes so complicated as to render the problem practically impossible, particularly if one desires to explore the whole multiplicity of the parameters and functions appearing in these equations.

12. DIFFERENCE-DIFFERENTIAL EQUATIONS.

Whenever the dependent variable, or its derivatives, in a differential equation are "retarded functions" of the independent variable t the equation becomes the so-called *difference differential equation*. Thus, for instance, if the angular velocity θ appearing in equation (1) is a retarded quantity $\theta(t - h)$, where h is the "time lag," this equation becomes then a difference-differential equation which can be written as

$$A\ddot{\theta}(t) + B\dot{\theta}(t - h) + C\theta(t) = 0. \tag{28}$$

This means that whereas $\ddot{\theta}$ and θ in this equation relate to the instant t, the quantity $\dot{\theta}$ relates to the retarded time $(t - h)$. This situation arises frequently in problems of modern automatic controls. Thus, for example, if a dynamical system characterized by the constants A and C is provided with some kind of artificially produced damping (coefficient B) introduced through a control system responsive to the angular velocity of the system, this damping frequently appears with a time lag h with respect to its theoretically correct phase ($h = 0$).

It is apparent that if one develops the function $\dot{\theta}(t - h)$ into a Taylor's expansion, equation (28) becomes of an infinitely high order. A differential equation of an infinitely high order can be discussed in terms of its characteristic equation which in that case is of an algebraico-transcendental form. The discussion can be conducted either graphically [17] or in the complex plane [18]. In practical problems very often these equations appear in a non-homogeneous form, that is when there is an external forcing function $f(t)$ on the right-hand side of equation (28) and when the coefficient B is a monotone-increasing function $B(\mu)$ of a certain parameter μ. It is observed, for instance, that for a simple periodic excitation, say $f(t) = K \operatorname{Sin} \omega_1 t$, and sufficiently small value of μ, the system behaves as an ordinary linear system. If the parameter μ is increased further there appear harmonics in the oscillation which generally have no relation whatever either to the externally applied frequency ω_1 or to the free frequency $\omega = \sqrt{\frac{C}{A}}$ of the system. If one continues to increase the parameter μ the form of the resultant oscillation becomes extremely complicated, evidencing the existence of numerous harmonics with incommensurate ratios so that the pattern of the oscillation ceases to be even of a pure periodic character (Fourier series) but is of a quasi-periodic nature. The origin of these complicated phenomena is due to the fact that the transcendental character of the problem [19] becomes more and more pronounced as μ increases. These

complicated phenomena are yet very little explored theoretically and constitute frequently a serious impediment to a proper solution of numerous engineering problems.

The application of the analogue for studies of the difference-differential equations is particularly simple. It is sufficient for this purpose to omit the term $b^2 f(\theta)\dot{\theta}$ in the arrangement described in Section 8 and to reverse the connections so as to retain only the term $+ \mu a^2 \dot{\theta}$. By introducing a suitable delaying action in the electronic circuit one obtains then easily the term of the form

$$+ \mu a^2 \dot{\theta}(t - h)$$

with which the difference-differential equation can be easily investigated for all values of its parameters μ and h.

13. DYNAMICAL ANALOGUE VERSUS COMPUTING MACHINES.

From the preceding it is sufficiently clear that the analogue on the one hand and the mechanical machines on the other do not pursue the same objectives and, for that reason, are not directly comparable. In the analogue each oscillation gives a new integral curve so that if a parameter is varied between two subsequent oscillations, a family of integral curves will be obtained very rapidly, although presumably with a moderate accuracy of, say, one or two per cent. depending on the degree of linearity of electronic circuits, accuracy of integration by the photo-integraphs and similar factors of a more or less physical nature. A mechanical computing machine, on the other hand, will produce an integral curve slower but with a higher accuracy.

Hence, in a totally unexplored problem in which the primary question is to ascertain the general qualitative aspect of integral curves for all possible values of the parameter variation or, possibly, for different form of the functions appearing as coefficients of the differential equation in question, the analogue will be probably preferable to a mechanical machine. On the other hand, a mechanical machine will be of a decided advantage when an accurate quantitative result is desired.

The accuracy of a mechanical machine depends mainly on its high-precision mechanical elements whereas in the analogue it depends on the linearity of circuits and similar factors. How far one can go in this direction is difficult to predict at present but it is likely that the electronic art will continue to develop further so that with new developments many things which seem to be difficult to obtain today will be feasible in the future. It seems to be fair to admit, however, that for a high accuracy work the mechanical machine will be superior to the analogue relying on the physical factors just mentioned. For that reason the two types of devices, the analogue and the mechanical machine, do not complete but rather supplement each other.

Another point to be mentioned is the fact that whereas a mechanical computing machine represents a capital investment of money, an ana-

logue of the type described can be made in an average physical laboratory without any high precision mechanical work, always expensive. Most of the problems involved in perfecting the analogue belong to the type of problems generally pursued in electrical or physical laboratories and may just as well fit into the program of an additional research in physics or electrical engineering. For these reasons the development of an analogue is more accessible to the institutions with a limited budget than undertaking the work of construction of a mechanical computing machine.

Another point to be mentioned is the fact that, whereas a machine is merely a mechanical contrivance establishing certain functional relations between the input and the output, the analogue produces a real physical phenomenon, an oscillation of a dynamical system, obeying a certain law prescribed by the differential equation in question. In view of this certain mathematical concepts such as singular points, for instance, will appear *naturally* in the analogue as certain *positions of equilibrium* (stable or unstable) whereas in a mechanical computing machine their presence will be ascertained only indirectly by the accumulation of points (in the differential analyzer) or figures (in an arithmetic computing machine) in a certain restricted neighborhood of integration. The same consideration applies obviously to similar critical conditions that may arise in a problem, such as the existence of limit cycles, separatrices, branch points of equilibria, etc. Such a closer contact with physics in problems which are of a physical origin may have some advantages in grasping the real situation.

This does not mean that the use of the analogue is limited to these problems only. In fact most any differential equation whose applications are totally unknown can be *interpreted* dynamically following this line of argument.

14. CONCLUDING REMARK.

Leonardo da Vinci once said that "mechanics is the paradise for the mathematician." This turned out to be true during the period of codification of theoretical mechanics. In recent times the gap between the mathematician and the engineer grew wider. Not every discovery in mathematics is immediately useful to the engineer, and, conversely, not every problem of interest to the engineer can be answered by the mathematician.

On the other hand, whenever contacts between mathematics and applied science occur, they are generally useful to both.

It cannot be denied that mathematics, at least in the early stages of its development, received a beneficial stimulus from some kind of physical "images." It is sufficient to recall the role played by the problem of a vibrating string in the genesis of the theory of partial differential equations, or that of the brachystochrone in the calculus of variation. Even in a codified mathematical doctrine a happy analogy frequently creates an added interest in the subject; a minimal surface of

the calculus of variation appearing in the form of a soap film undoubtedly contributes better than anything else to the intuitive grasp of the abstract subject by the student.

Viewed from this standpoint a systematic study of analogues may not only bridge the gaps separating the mathematician and the engineer but may, in some cases, orient a purely analytical argument as well. It is recalled that the work of Poincaré has estabished that periodic solutions of non-linear differential equations may exist for small values of the parameter μ in equation (17). There was no analytical certainty whatever as to the existence of such solutions for large values of μ until a physical "image," the electron tube oscillator, in hands of Van der Pol has shown that such solutions may exist even in this case. This, in turn, oriented the analysis along somewhat new lines (10).

An analogue capable of producing an unlimited number of such "images" may be just as useful in a purely mathematical work as in applied science, at least as an initial stimulus for the mathematical argument. In fact, it is sufficient to take any differential equation, to replace the conventional y, the dependent variable, by θ and x, the independent variable, by t to be able to form an idea as to how the dynamical "image" should be produced by the analogue. Once this motion is produced, one has by this very fact the qualitative picture of solutions. In this case the fact that the solutions are known to within a few per cent. of accuracy will probably be of no importance inasmuch as the principal object of these studies will be to initiate a purely mathematical argument once the general qualitative aspect of integral curves has been ascertained.

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Huge Spot Welder Ups Production 3,000%. (*The Welding Journal*, Vol. 25, No. 10.)—Development of a new huge multiple spot-welding machine, one of the largest of its type known in existence today, has been announced by Pullman-Standard Car Manufacturing Co.

The new machine is in operation at the Company's Car Works plant in Chicago where welding engineers say it will increase production in the department about 30 times, or 3,000%, over present processes.

Weighing more than 90,000 lb. the huge machine was built for Pullman-Standard by National Electric Welding Machines Co. of Bay City, Mich. It was developed after extensive study of all existing methods by development engineers of both Pullman-Standard and the builders.

The machine will be used primarily to weld "stiffeners" to the interior of car sides to give them the sleek appearance dictated by today's flashy colored streamliners. Engineers explain that a "stiffener" is not visible, but is a sheet of light gage corrugated metal which is welded inside the walls of the car to lend strength and smoothness, much on the same principle as the corrugation on the interior of a cardboard box, making it many times more sturdy than the wall alone.

The use of corrugated stiffeners in car building was patented by Pullman-Standard in 1938 and the first system of fabrication employed single, stationary spot welders making one weld at a time. These were used until 1942, when the war suspended all car building. The principle of applying multiple spot welding to this work was developed during the war period and with the advent of postwar car building the new machine was built.

In operation, a metal table 30 ft. long and 10 ft. wide travels beneath a battery of 48 stationary welding electrodes. The work to be welded is laid flat on the table, which has been covered with a copper plate. As the table moves slowly beneath the row of spot-welding electrodes it is adjusted to stop at proper intervals and the electrodes automatically lower, making contact with the work and securely welding the "stiffeners" to the car side. The electrodes then lift up and the table moves on to the next position, where the process is completed.

A unique electric eye arrangement makes the operation entirely automatic. Along one side of the table are drilled two rows of small holes about ¼ in. apart. The electric eye beam is directed from beneath the table, through these holes, and when striking a photoelectric cell above the holes, the circuit is completed which stops the table, lowers the electrodes, makes the weld, lifts the electrode and starts the table into operation.

By dropping loose rivets into all the holes not needed in the operation, the position of welding is preset. The table then moves along smoothly until an open hole passes over the light ray, setting the welding process into operation.

R. H. OPPERMANN.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

REVISION OF ELEVATOR SAFETY CODE.

The American Standard Safety Code for elevators, dumbwaiters, and escalators, sponsored jointly by the American Institute of Architects, the National Bureau of Standards, and The American Society of Mechanical Engineers, is now being revised. As a result of the better code requirements in the American Standard Elevator Code and the testing and certifying of these safety devices, the number of elevator accidents throughout the United States has shown a steady decrease during the past 20 years, although the number of elevators in use has increased materially.

The usual periodic revision scheduled for 1943 was held in abeyance due to the pressure of war work. The 1947 edition is expected to be clearer in intent and fuller in coverage than previous editions, and will be arranged to require the minimum number of cross references. At present ten subcommittees are at work on particular phases of this revision.

Subsequently, after several years of research work at the Bureau, test specifications were set up for undercar hydraulic buffers, approved by the Sectional Committee and included in the 1931 edition of the code. Type tests on such equipment are made by the National Bureau of Standards. Where an interlock or buffer meets code specifications, a certificate of compliance is issued. Such certified interlocks and buffers are required by a number of states and cities as well as by various branches of the Federal Government.

For 25 years the National Bureau of Standards has taken an active part in the preparation of this important standard. In 1922 the Bureau was asked to set up equipment for testing elevator hoistway door interlocks. To provide the necessary data, a survey of several thousand elevator landings equipped with interlocks was made by Bureau engineers. Test procedure to detect some of the commoner weaknesses and causes of failure found during this survey were prepared by the Bureau and these test specifications approved by the Sectional Committee with minor modifications. They have remained substantially unchanged since that time. Equipment which meets these tests may be expected to have reasonably long life even under adverse conditions such as moisture, lack of lubrication, etc. Of greater importance from the safety standpoint, any mechanical or electrical failure of such device will not cause unsafe operating conditions.

* Communicated by the Director.

HIGH WET-STRENGTH PAPER.

A new paper, possessing unusual qualities that made war maps durable in the water, mud, and grime of the battlefield, was developed early in the war by the Army Engineers in cooperation with the National Bureau of Standards. High wet-strength, obtained by the relatively new development of resin bonding, constitutes the most important feature of this paper, which is resistant to conditions that disintegrate conventional papers. Following the developmental and semi-commercial paper making experiments, the Bureau played an important role in carrying the new type of paper into commercial production. Though developed primarily for war maps, this high strength paper offers numerous yet unexplored peacetime uses—such as for bed sheets, bath mats, washable towels, wrappings for wet meats and vegetables, and outdoor advertising.

The specifications for this paper were very stringent. They called for the rugged strength—dry, wet, or oil soaked—that gives maps their durability. In addition, they called for low expansivity; high opacity whether wet, dry, or oily; good writing quality wet or dry; low acidity; and smoothness suitable for printing multicolor line maps and 200-line photomaps. Close limitations were placed on thickness, weight, and moisture content. Experiments at the Bureau determined how such paper could be made from available raw materials.

The extremely high strength required for the map paper made it essential that all or a large proportion of the fibers used be of high strength. Rag fibers were not considered because neither an adequate supply of rags nor sufficient rag-cooking equipment was available to meet anticipated needs. Hence, the experiments were confined to commercially-available bleached wood pulps: three types of bleached sulfates, bleached sulfite, deciduous wood soda, and deciduous wood sulfite.

Experimental papers using these pulps were made in the Bureau of Standards pilot paper mill which is semi-commercial in size, and adapted to the experimental manufacture of papers under conditions which simulate those of industrial plants. The manufacturing process for the high wet strength paper follows the same steps used in making conventional paper, the only differences being a shorter beating cycle and the addition of resin bonding. The key to the high strength paper is the melamine-formaldehyde resin, which is added continuously to to the stock leaving the screen just before it enters the head box of the paper machine. The resin is added as a colloidal solution—made by dissolving resin in the form of a fine white powder—in warm water acidified with hydrochloric acid. The solution is uniformly mixed with the stock by baffles in the head box, where the temperature is maintained at 90° F. $\pm$ 2° at that point.

REVISED BUILDING CODE.

Safety factors, which must be kept in mind in the drive to increase the supply and reduce the cost of housing, are stressed in a new publication on building code requirements issued by the National Bureau of Standards, acting in a consultant capacity for the National Housing Agency.

The proposed code aims at providing sound construction without excessive cost and with adequate provision for recognizing new developments in construction techniques and materials as they occur. The proposals cover such matters as design loads for floors, wind pressures on roofs and walls, snow loads, working stresses for building materials, fire protection, design of chimneys and fireplaces, precautions concerning installations of heating appliances, and simple measures to prevent injuries due to improper construction. Such a code, dealing with safety matters only, will not assure a buyer or occupant of a house that the structure will be satisfactory in all respects, but it is felt that there are many features of a house which, if meeting adequate safety requirements, will also give good performance otherwise.

Identified as Building Materials and Structures Report BMS107, copies of this publication are now available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at twenty cents each.

STEEL PLATES FOR WELDED SHIPS.

The strength of large welded steel structures, brought into prominence during the war by Liberty ship failures, is being investigated by the Structural Steel Committee of the Welding Research Council in cooperation with the Engineering Mechanics Laboratory of the Bureau. Tests already concluded indicate that factors of design, as well as welding, have an effect on the initial formation of a crack. The continuation of a crack depends upon the notch sensitivity of the steel, a property overlooked in past specifications for ship plate.

Six 9-ton welded structural carbon steel box-girders of 22-foot span, with an overall width of 2 feet 6 inches and depth of 2 feet 1.5 inches, have been constructed at the Ingalls shipyard, Pascagoula, Miss. Very abusive welding procedures and sequences were used, along with some unfavorable details of design, for the deliberate purpose of producing the highest possible residual stresses, especially in the vicinity of the transverse closing butt of the tension flange, which was welded last under extreme conditions of restraint. The tension flange plate is fitted between the side web plates to simulate the joints between the deck of a ship and the side plating when the ship is subjected to "hogging" stresses (with an elastic curvature that is convex upwards).

The girders have been successfully proportioned to insure against failure by lateral deflection and buckling or twisting, the manner in which test beams and girders usually fail. The compression flange was made 2½ inches thick.

The first girder, constructed of ordinary semi-killed structural steel hull planting taken from stock in the shipyard, was tested at room temperature. It failed by rupture with a brittle or "cleavage" type of fracture and a sudden release of energy that shook the building. Failure did not occur until the measured strains and elastic deflection indicated extreme fibre stresses approximately equal to the conventionally determined ultimate tensile strength of the material, not far below the modulus of rupture of 75,600 pounds per square inch as computed for the breaking load of 1,397,000 pounds and corresponding bending moment of 71,200,000 pound-inches. Total deflection at failure was about 8 inches, about 7 being permanent set and less than 1 inch elastic deflection.

The second girder, of fully killed steel, tested at about −45° F., failed in a similar fashion, but the fracture was more of a compound, shattering type under the influence of cold temperature, and the entire girder snapped in two. The breaking load of 1,165,000 pounds was only 16.5% lower than that for the first girder although it was 30.9% lower than the maximum load imposed upon the third girder, which was tested at room temperature.

The third girder, of fully killed steel, did not fail under a load of 1,685,000 pounds, equally distributed between two load points 2½ feet on either side of the mid-span, when the center deflection reached 18.06 inches. At this point, the girder was almost touching the supporting girders of the test apparatus, and further loading was impossible. The permanent center deflection after removal of the load was 16.45 inches. The extreme fiber stresses, computed under this loading, were 91,200 pounds per square inch in the projections of the side plates and 70,200 pounds per square inch in the tension flange plate. It is probable that 70,200 pounds per square inch stress was actually realized. Data like the extensive strain gage readings still remain to be analyzed.

The purpose of the research program is to investigate, at various significant temperatures, (1) the effect of severe geometrical constraint against ductile behavior and upon the capacity of a welded structural member for resisting rupture under external load, and (2) to observe the detrimental effects of residual stresses.

The character of future tests has not been decided. The testing of girders preheated during welding, testing at various intermediate temperatures, and studies of the effects of normalizing heat treatments subsequent to construction of the girders, are all contemplated. Out of these tests, a fuller knowledge of the behavior of large welded steel structures and data that may lead to the design and construction of more satisfactory members are expected.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, LECTURE HALL, WEDNESDAY, JANUARY 15, 1947, 8:15 P.M.

The Franklin Institute held its Annual Meeting in the Lecture Hall on Wednesday evening, January 15, 1946. Mr. Richard T. Nalle, President, presided at the meeting. There were approximately 349 people present.

The minutes of the Stated Monthly Meeting for November had been printed in full in the December issue of the JOURNAL and therefore were not read. The President stated that if there were no corrections or additions, the minutes would stand as printed. The minutes were approved.

The President then presented, in resumé, his annual report, touching on outstanding events in the progress of the Institute during the year of 1946.

The Secretary, Dr. Henry B. Allen, was then called upon. He gave the report of the Membership Department with reference to new admissions,

The following members were elected in the month of December, 1946:

Honorary	1
Active Life	1
Active	46
Associate	22
Student	33
	103
Total Membership as of December 31	5,562

The Secretary then read the report of the tellers, Mr. James D. Lee, Jr., Dr. George S. Crampton, and Mr. J. Logan Fitts, for the annual election which showed the election of the following officers and members of the Board of Managers.

President	Richard T. Nalle
(One year)	
Vice-Presidents	Walton Forstall
(One year)	W. Chattin Wetherill
	S. S. Fels
	Richard W. Lloyd
Treasurer	M. M. Price
(One year)	
Managers	G. H. Clamer
(Three years)	Clarence L. Jordan
	Ralph Kelly
	Lionel F. Levy
	Charles Penrose
	James H. Robins
	Philip C. Staples
	Philip H. Ward, Jr.

The Secretary then pronounced these gentlemen as duly elected to their respective offices for the period indicated.

The President then expressed his appreciation to the tellers for their service to the Institute. He also thanked the members for their vote of confidence in him in electing him to the

office of President. He then expressed the same sentiments on behalf of the other officers on the Board of Managers.

The Secretary then addressed the President stating that upon nomination by the Board of Managers, The Franklin Institute, at their meeting held on December the 18th, elected Dr. Vannevar Bush to Honorary Membership in The Franklin Institute, "in recognition of his distinguished scientific work and his signal contributions to the war effort." The Secretary presented Dr. Bush saying that,

"Dr. Bush is a native of Everitt, Massachusetts. He was graduated from Tufts College in 1913 and in 1916 was awarded the degree of Doctor of Engineering from Harvard University and the Massachusetts Institute of Technology.

Dr. Bush was invited to join the Faculty of the Massachusetts Institute of Technology in 1919 as Professor of Electric Power Transmission. He was appointed Vice-President and Dean of the School of Engineering of the Institute in March, 1932. At the same time he was elected a member of the Corporation of the Institute.

In 1943 he was awarded the Edison Medal, the American Institute of Electrical Engineers highest honor.

In 1939 Dr. Bush became President of the Carnegie Institute and while still retaining this position he was, in 1940, appointed by the President as Chairman of the National Defense Research Committee. A year later he was made Director of the Office of Scientific Research and Development charged with the duty of mobilizing the scientific effort. Recently he was made chairman of the Federal Research and Development Board.

Dr. Bush has been particularly interested in the design of advanced mathematical analyzing instruments and has had charge of a group of research workers which has produced several important instruments of this type. In recognition of work in this field, in 1928 he was awarded the Levy Medal of The Franklin Institute. Recognition has also been given him on account of the design which he developed of an intricate analyzing machine called the Differential Analyzer. This machine greatly increases the speed of scientific and engineering calculations.

Dr. Bush is the author of a number of books including 'Science, the Endless Frontier' and 'Endless Horizon.' He has received Honorary Degrees from many universities, including Harvard, Yale, Johns Hopkins, and Pennsylvania."

The President then awarded Dr. Bush the certificate of Honorary Membership. Dr. Bush thanked the President. The President then presented Dr. Bush, who addressed the audience on "Civilian Science and Military Thinking; and the Joint Research and Development Board."

At the end of Dr. Bush's talk the President thanked him and the meeting was adjourned with a rising vote of thanks to the speaker for his interesting lectures.

HENRY B. ALLEN,
Secretary.

ANNUAL REPORT OF THE PRESIDENT TO THE BOARD OF MANAGERS FOR THE YEAR 1946.

The By-Laws of the Institute provide that the Board of Managers shall present through the President, at the Annual Meeting of the Institute, a report of the condition of the affairs of the Institute. The following report has been prepared by the President to fulfill this provision.

At the meeting of the Board of Managers on November 20, 1946 Charles S. Redding submitted his resignation as President of the Institute. It was accepted with regret and the thanks of The Board for his five years of constructive leadership and Richard T. Nalle, Executive Vice President of the Midvale Company and a Vice President of the Institute, was elected by the Board to fill the vacancy. Mr. Redding was elected to the Board, there being a vacancy.

The main problems facing the Institute in the year just passed were those connected with reconversion from war time conditions to those of peace time economy. The Institute has

been concentrating all if its effort, since the beginning of 1942, wherever they could serve, to help win the war. Study had to be made therefore toward restoring the activities of the Institute and principally the museum to peace time service. At the same time concentrated effort has been given to continuing the research laboratories established during the war, not only for useful service to industry, but for peace time national defense preparedness and also because they furnish "life blood" to the Institute through reduction of overhead, thus helping to bridge the gap between overall operating expenses and inadequate income.

The year 1946 closed with the property of the Institute entered on its books at *$5,921,000*, an increase of $141,500 for the year. Of this amount, real property (building equipment, not including donated museum exhibits) amounts to *$4,241,300*, a $116,000 increase, and personal property (securities and cash) come to $1,679,700, an $8,900 increase.

The Institute's investment in securities at the close of the year showed the value of:

	1946	*1945*
Available as to income only	$ 696,000	646,400
Unrestricted	$ 916,000	914,400
	$1,612,000	1,560,800

The principal items of income and expenses resulting from the operation of the Institute for the year are closely as follows. The final figures however will not be available until the books are finally closed following audit some weeks hence.

Income	*1946*	*1945*
From:		
Dues	$ 55,800	$ 57,000
Admissions	62,500	48,800
Investments	66,800	60,400
Other sources	96,400	98,300
Friends of Franklin	21,100	25,400
Research Contracts	875,100	708,000
Total	$1,177,700	$997,900
Expenses		
General	$ 246,700	$215,600
Museum Operation	121,300	123,400
Library	20,500	18,500
Publications	18,300	18,000
Meetings	2,800	2,200
National Franklin Committee	1,800	3,500
Other	10,200	6,500
Research Contracts	651,800	571,100
Laboratory Administration	19,100	—
Total	$1,092,500	$958,800
Gain for the year	$ 85,200	$ 39,100

The group of 250 citizens known as Friends of Franklin have again come to our aid through their generous contributions as indicated under the income figures noted about. They form an important, and we trust continuing, group.

Including the required Stated Meetings of the Institute, 19 were held in all during the year, at which times notable technical papers were presented. Some of these meetings were held jointly with other technical societies. This cooperation has become increasingly popular. The average attendance for all of the meetings was 244, which is our highest record so far.

Our total membership at the close of the year was 5,562, a net increase of over 100 during the year. This net gain reflects the activities of the Membership Committee and the untiring efforts of the Membership Department.

The Membership Committee started, early in the year, a series of popular talks under the heading of "Science is Fun." These talks were preceded by dinners and proved highly successful. They filled a long felt need for programs designed specifically for those members of the Institute for whom the regular technical meetings hold no great appeal. They covered recent scientific developments in every day materials for the post-war world.

Museum.

In 1946 our efforts were concentrated on appraisal, planning, and organization. Mr. R. W. Lloyd resigned as Executive Director of the Museum on January 23, and was succeeded, on July 1, by Mr. A. C. Carlton who was associated with the Chicago Museum of Science and Industry from 1932 to 1941 and with the Chicago Ordnance District from 1942 to June 1946. It was the consensus of our staff that the addition of a small group of trained lecturer-demonstrators would contribute greatly to the value of the Museum. As the initial step in the organization of this group, Miss Lucia Keim was appointed, on December 16, to formulate plans and subsequently to organize and operate the group.

The attendance trend is encouraging. The following tabulation shows Museum attendance and Planetarium attendance for the first 11 months of 1944, 1945, and 1946.

	Paid	*Free*	*Total*
Museum			
1944	111,411	38,994	150,405
1945	130,830	50,676	181,506
1946	149,939	40,824	190,763
Planetarium			
1944	59,554	27,166	86,720
1945	55,729	31,917	87,646
1946	82,608	34,323	116,931
Museum and Planetarium			
1944	170,965	66,160	237,125
1945	186,559	82,593	269,152
1946	232,547	75,147	307,694

Those persons who visited both Museum and Planetarium were sold two tickets each and hence were counted twice. Test runs indicated that roughly one-fifth of our visitors purchased two tickets. Therefore the actual numbers of persons who visited the Institute were roughly one-fifth less than those shown in the preceeding tabulation. On December 1, the rate structure was modified. Effective that date a single $.50 ticket admitted the bearer to both Museum and Planetarium. The following tabulation shows Museum plus Planetarium attendance during December of 1944, 1945, and 1946, Statistics for 1944 and 1945 are approximate and are based on 80% of Museum plus Planetarium attendance.

	Paid	*Free*	*Total*
1944	21,661	12,050	33,711
1945	22,959	9,414	32,373
1946	26,091	11,131	37,222

The rate change was made to increase income. December 1945 income was $5,551; December 1946 was $9,176. The percentage increase was thus 65%. It is believed that income from admissions in 1947 will be higher than in 1946, but that the percentage increase will be considerably lower than the 65% obtained in December 1946 which is not considered typical because of the great popularity of the Christmas Planetarium lecture.

A total of 963 Planetarium lectures were given in 1946. This number includes 55 lectures given to school children. Special lectures with additional apparatus, music and lighting effects, were given in February (Stars and Atoms), April–May (Trip to the Moon), and December

(Star of Bethlehem). The Amateur Telescope Makers' activities increased markedly. At the present time more than one hundred individuals are participating.* In October the United States Coast and Geodetic Survey requested the Institute to cooperate in their microseisms program for long range prediction of great storms which was initiated on January 1, 1947.

Our Industrial Cooperation program has been in effect for over six years. The number of participating companies and the total contributions received therefrom were substantially the same in 1946 as they were in 1945 (100 vs. 98 and $24,000 vs. $23,000). During 1946, new Industrial Cooperation exhibits were installed by Hamilton Watch Company (Timekeeping), Builders-Providence, Inc. (Venturi Meter), and Standard Oil Company of Pennsylvania (Link Trainer).

Early in the year an improved model of a Link pilot flight instrument trainer was installed and has proved to be one of our outstanding visitor-operated exhibits. A P-51 pursuit plane was placed on display in December. Major improvements or repairs, costs of which were borne by exhibitors, were completed in 1946 on exhibits sponsored by Elgin National Watch Company (escapements), Warner and Swasey Company (McDonald Observatory), Pennsylvania Salt Company (salt and its products), Sun Oil Company (Petroleum), Edward G. Budd Manufacturing Company (Stainless Steel), and Westinghouse Electric Corporation (Surge Generator).

A temporary exhibit of "Mystery" clocks was displayed in the Planetarium Lobby during October. Other exhibits were displayed in November and December. These "exhibits-of-the-month" have been quite popular and we propose to continue this program.

During 1946 seven industrial companies sponsored photographic exhibits in the Industrial Photographic Gallery.

The Marriner lecture-recitals were resumed in January, and have been well attended.

The Department of Museum Education continued its activities at an accelerated tempo. The upward trend in attendance by school children who visit the Museum and Planetarium in groups continued satisfactorily in 1946.

Number of Children in Groups who were...

	Admitted free (Philadelphia public and parochial schools)	*Admitted at 60% of full admission rate (Philadelphia private schools and all non-Philadelphia schools)*	*Total*
1943	15,000	17,472	32,472
1944	33,633	27,225	60,858
1945	42,675	38,868	81,543
1946	52,140	64,396	116,536

Attention is invited to the fact that the 1946 attendance was almost four times as great as the 1943 attendance.

Work with school teachers was stressed throughout the year. The Department cooperated not only with the State Teachers Colleges of Pennsylvania and New Jersey, but with the Schools of Education of other nearby colleges. Particularly noteworthy has been the cooperation between the Institute and Temple University and the University of Pennsylvania. Virtually all of these sessions have been devoted to a discussion of increased use of the Museum as an aid in classroom teaching. Certain sessions of the University of Pennsylvania's annual Schoolmen's Week program were held at the Institute and were attended by educators from many distant points.

* A 20 inch mirror was completed in December. This project has been under way for seven years as a cooperative undertaking of some thirty members of the group. It is hoped that some suburban school can be interested in mounting and housing the mirror in order that it may be used by the students, the local townspeople, the members of the ATM, and The Institute Staff.

With the cooperation of the curriculum office of the Philadelphia Board of Education, a series of lectures was given in an In-Service Training program on the most effective use of the Museum and its facilities. A number of faculty visits were held in the Museum, at each of which a tour of some portion of the building was conducted to exemplify the way in which teachers might prepare themselves and their classes before study visits. Conferences were held with many teachers to discuss utilization of their museum tour in the classroom both before and after their visits.

During a part of the year, the Museum Teacher assigned to the Institute devoted time to the development of classroom projects in visual education correlated with The Institute and the curriculum of the Board of Education. A Committee from the Board of Education spent considerable time in studying the Museum in order to procure information in connection with its use in specialized subjects and a meeting was held in our Lecture Hall to transmit this information to the interested supervisors of the city.

Because of the interest expressed in the little jingle book prepared the previous year for young people, a revised edition was issued and titled "How to Find Your Way Through The Franklin Institute." This has had a very large sale not only to the young people for whom it was planned, but also to adult visitors.

Not only was a large number of students booked for the regular Planetarium shows, but 55 special shows were presented specifically for schools. Attendance at these shows has averaged very close to capacity. It is noteworthy that during the entire year there was not a single failure of a group to take up the reservation it had made for these special shows.

The "Science is Fun" radio program began its third year in September, with the issuance of an excellent teacher's manual which was distributed to all elementary schools in the Philadelphia area. A member of the Department of Museum Education participated in these broadcasts, as well as in programs over other stations.

The Christmas Week Lectures under the James Mapes Dodge Foundation were devoted to the subject of "Weather" and attracted an enthusiastic audience.

The Library has been increased by 1,500 new volumes which were acquired by purchase or gift. The additions were as follows:

	Bound Volumes	*Unbound Volumes*	*Pamphlets*	*Maps*
By Gift	195	223	943	150
Binding				
Magazines and Society Transactions Patents	166			
	485			
Purchase	450	36		
	1,296	259	943	150

Total addition of all kinds: 2,648.

Gifts were received from: Dr. Henry B. Allen, Mr. L. R. Wilson, Mr. K. T. Keller, Mr. W. Ashworth, Mr. F. Price, Mr. D. Gutleben, Mr. F. M. Chapman, Miss M. Bache, Mr. S. H. McVitty and many industrial companies, societies, and institutions.

The Library is now receiving many of the foreign periodicals which were discontinued during the war years and, with the addition of several new subscriptions, this material has been called for and used extensively by our readers.

Patent specifications were received regularly from the United States, Great Britain and Switzerland, and this material was requested daily.

The Library continued to operate on the same schedule and many readers took advantage of our evening hours. There were 12,600 persons who used the Library last year and due to the increased number of readers over that of 1945 the Library Staff was obliged to handle much more material for reference use. Circulation and photostat orders increased. Orders for photostats were received daily. There were 16,500 prints made during the year, approximately 3,000 more than the previous year. The many questions which were asked by mail and telephone required a good deal of time for research so that they could be answered satisfactorily.

The Library Staff gave the best possible service to its readers although they were required to do much research work.

There were 1,436 volumes of non-technical nature withdrawn from the Library.

The total contents of the library as of January 1, 1947 was:

129,785 Volumes
46,332 Pamphlets
4,272 Maps

During the past year 10,513 members and 2,093 non-members consulted the Library. There were 6,980 telephone calls for technical information.

The Library Committee and the Library Staff gave much assistance to the Institute members and co-employees who consulted the Library during the past year.

The service rendered by the Members of the Committee on Science and Arts lived up to their century-old high standard. During the year the entire committee met nine times while 41 Sub-Committee meetings were held. Ten medals and one certificate of merit were awarded at the Annual Medal Day exercises in April. The two Franklin Medallists were Dr. Henry C. Sherman and Sir Henry Tizard.

During the year we received a call from one of our former medallists to whom an award was made in 1941, a Frenchman (Dr. Lyot). Although his medal and certificate had been forwarded to him before, France was overrun by the enemy and he had never received them. We were only too glad to furnish him duplicate copies.

Toward the beginning of this report reference was made to the important activity of the Institute built up to an impressive extent during the war; namely the applied science research. During the year this was formally organized as the Franklin Institute Laboratories for Research and Development. Our work for Government departments is continuing, and at the same time, activity in industrial work is increasing.

During the war the effort was devoted almost wholly to projects for the Armed Forces, but equal emphasis is now being placed on industrial research. The Franklin Institute Laboratories for Research and Development have been formally established and organized into the following four main divisions.

MECHANICAL AND CIVIL ENGINEERING
ELECTRONICS AND INSTRUMENTS
CHEMICAL ENGINEERING AND PHYSICS
ADMINISTRATIVE

Today, both Government and Industrial projects are prosecuted by a well balanced, technically qualified staff of scientists and engineers, the majority of whom have had extensive industrial experience, and are competent to deal with problems in the areas indicated.

The staff grew from 119 in March 1946 to 246 as of this date, and is still expanding. This growth is approximately proportional to the dollar value of expenditures on research contracts which cover both Government and Industrial work.

Additional space has been obtained to make room for the expanding activities, and the Court Building partly remodeled and placed in operation. Modern scientific equipment is gradually being added to augment the Laboratory facilities.

Serious problems, as was expected, have been encountered in meeting space requirements for the expanding activities, in obtaining the required equipment, and in securing the desired additional scientific personnel. These problems are being solved, and we look forward to a year of continued achievements in The Laboratories.

It is anticipated that gradual expansion in personnel and facilities will continue for some time. As a part of The Franklin Institute, and therefore sharing in its tradition of integrity of scientific effort, The Laboratories for Research and Development are in an enviable position to carry forward projects in the fields of the physical sciences.

The Bartol Research Foundation has been fortunate in securing a Navy contract, in which work of an entirely unrestricted nature and of a type consistent with the Foundation's normal interest is being carried on in three branches of nuclear physics.

The work of a second Navy contract is in progress and certain contracts have been completed. The Cosmic Ray observations reported last year, as contemplated in a B-29 Bomber, have been successfully completed and have led to important conclusions as to the nature of the Rays. Also the Foundation has Cosmic Ray apparatus on Commander Finn Ronne's expedition to the Antarctic and plans participation, through cosmic ray observation, in the National Geographic Society's forthcoming expedition to Brazil to view the eclipse. It has also been asked to participate in the forthcoming flight by Jean Piccard under the auspices of the Navy.

The Biochemical Research Foundation completed its work carried on during the war with its cyclotron for the Manhattan District and has now returned to its vitally fundamental work on Biochemical problems related to cancer.

The National Franklin Committee has continued to disseminate the knowledge of Benjamin Franklin. During the year more than 24,000 pamphlets, prepared by the Institute, were distributed to schools, organizations, and individuals. The increasing number of times Franklin is being quoted in the press and over the radio leads us to believe that our work is bearing fruit. This work was, for the latter half of the year, carried out by the Institute's Public Relations Department in addition to their regular excellent service to all other activities of the Institute. This change was brought about by the resignation of Miss Elizabeth D. Connelly, who had for many years served the Institute faithfully.

The Hostess Committee took full charge of the reception preceding Medal Day on April 17th, with approximately twenty-five members of the Committee in attendance.

On May 27th they gave a special luncheon in honor of Col. Charles H. Greenall, newly elected Executive Director of The Franklin Institute Laboratories for Research and Development, and Mrs. Greenall.

On October 4th, prior to the Vermilye Medal Dinner, the Hostess Committee gave the reception in honor of the medallist, Martin W. Clement.

At its October annual meeting, Mr. A. C. Carlton, newly appointed Executive Director of the Museum, and Mrs. Carlton were special guests at the luncheon following the meeting.

At the annual meeting on October 17th Mrs. John White Geary was reelected Chairman, and Mrs. Isaac A. Pennypacker, Vice-Chairman for the coming year. The following were elected members of the Executive Committee:

Mrs. John C. Atwood, Jr.
Mrs. Gideon Boericke
Mrs. Newell C. Bradley
Mrs. Robert H. Dechert
Miss Mary DeHaven Dercum
Mrs. John Hyland Dilks
Mrs. Crawford H. Greenewalt
Mrs. James S. Rogers
Mrs. William S. Scull, 2nd

The Annual Christmas Tea was held in the Board of Managers room on December 12th. All attended the Planetarium Christmas showing of the Star of Bethlehem prior to the Tea.

Metal furniture for the outdoor lounge was given to the Institute by the Hostess Committee, which was purchased with surplus funds in their treasury.

Our sincere thanks is extended to the Hostess Committee for their services. It is expected that they will be asked to help more and more as our post-war activities develop.

A severe loss to our Board of Managers and the Institute was suffered in November through the death of Edward G. Budd. Mr. Budd always prided himself on having received his first technical training in the old schools of The Franklin Institute.

The above concludes the factual part of the annual report. I think it a very appropriate place to extend the thanks of all interested in the well being of the Institute to ex-President Charles S. Redding for his able leadership during the past five years. In this time, many changes have occurred and difficult operating conditions have been met and overcome. Contribution has been made to the success of our Armed Forces. Plans have been well laid under

his guidance for constructive advancement of the Institute in scientific achievement and toward a self-sustaining position. He well deserves the thanks of all of us for his many contributions.

The start of our 124th year finds the Institute with the largest and most talented staff it has ever had and all with great enthusiasm for the tasks which lie ahead. At the end of the year the Institute, exclusive of the Bartol and Biochemical Foundations, had 390 persons on its payroll. This number includes 240 in the Laboratories. Many problems remain to be solved, but I am confident that with the help, as always, of Dr. Allen and the entire organization, satisfactory progress will be made.

The Board of Managers is sincerely grateful to the staff for their faithful work during 1946.

For the Board of Managers

RICHARD T. NALLE,
President.

BY-LAWS

ARTICLE I

STOCK.

Section 1. The Real and Personal Estates of the Institute as held upon the First day of January, One Thousand Eight Hundred and Eighty-one, shall be valued at One Hundred Thousand Dollars, and shall be represented by Ten Thousand Shares of Stock of the par value of Ten Dollars each. Said shares shall be divided into two classes, *viz.:*

First Class. Shares not registered for use: on which no annual payment shall be charged or collected, and the holders thereof shall not have the privileges of members of the Institute, but may, if of legal age, vote at any annual election for officers and managers upon the payment of One Dollar upon each share of stock on which they may desire to vote; provided, however, such shares have been held by the same person at least three months before such election.

Shares of the First Class may be converted into shares of the Second Class at the pleasure of the owners, provided the transfer be approved by the Board of Managers; but, when once so converted, they shall always continue in the Second Class.

Second Class. Shares registered for use: on which Twelve Dollars per annum shall be due and payable from resident members in advance on the first day of October in each year, except as hereinafter provided.

Non-resident holders of Second Class stock shall pay an annual fee of Five Dollars.

Section 2. The holders of Second Class stock shall be entitled to the use of the library, lectures and reading-room; and, if of legal age, to all other privileges of membership in the Institute, so long as they make the annual payment in advance; and shall, on the payment of One Dollar therefore, be entitled to a Certificate of Membership.

Section 3. If the annual dues for successive years remain unpaid at the expiration of two and a half years on any share of stock of the Second Class, such shares shall then become forfeited to the Institute; but such forfeiture may be remitted by a unanimous vote of the Board of Managers.

Section 4. Stock of the Second Class may be held in trust for persons not of legal age, and shall be liable to the payment of only one-half the annual fees due upon stock of Second Class held by persons of legal age; provided, that when such minors arrive at legal age, new certificates, subject to the full annual contribution, shall issue on payment of the customary fee.

Section 5. Certificates for the First Class stock may be issued for any number of shares in a single certificate; but every certificate for the Second Class shall be for one share only.

Section 6. No share of stock in the Second Class shall be transferred until all arrearages and fines are paid, and all books and tickets returned, and the transfer approved by the Board of Managers.

Section 7. All certificates of stock shall be signed by the President and Secretary; shall be issued by the Controller, and shall be transferable only on the books of the Institute by the owner, or his legal representative, on the surrender of the old certificate, and of a fee of twenty-five cents for each certificate.

Section 8. All subscriptions to stock shall be approved by the Board of Managers before the certificate can be issued.

ARTICLE II.

MEMBERS.

Section 1. All persons interested in the purposes and activities of the Institute and willing to further them may become members when elected by the Board of Managers, or in a manner prescribed by the Board, except as qualified by Section 6 of this ARTICLE. Membership shall consist of the following classes:

1. Student members
2. Associate members
3. Active members
4. Sustaining members
5. Honorary members

The Board of Managers may establish other classes of members, provided that the privileges enjoyed and dues paid by such other classes are not inconsistent with the privileges and dues of the classes of members specifically provided for by these By-Laws.

Section 2. Student members shall be under twenty-five years of age and shall pay annual dues of $2.00. They shall be entitled to unlimited free admission to the Museum and the Planetarium. Student members who are fourteen or more years of age may, if endorsed by a teacher or an Active member, have the use of the library upon the payment of additional annual dues of $1.00 but shall have no voting privileges or rights to hold office.

Section 3. Associate members shall pay annual dues of $5.00. They shall be entitled to unlimited free admission to the Museum and to the Planetarium, but shall have no voting privileges or rights to hold office. Upon the payment of $5.00 additional annual dues they shall have Family privileges as defined in Section 7 of this ARTICLE.

Section 4. Active members shall be not less than twenty years of age. They shall pay annual dues of $15.00. Active members, residing permanently at a distance of fifty miles or more from Philadelphia, shall pay annual dues of $7.50. Active members shall be entitled to use the library, to receive one copy of the Journal of The Franklin Institute, to vote and to hold office. They shall be entitled to all the privileges of Associate members and upon the payment of $5.00 additional annual dues shall be entitled to Family privileges.

Section 5. Sustaining members shall be not less than twenty years of age. They shall pay annual dues of not less than $50.00. They shall be entitled to all of the privileges of Active members and shall have Family privileges as defined in Section 7 of this ARTICLE free of additional charge.

Section 6. Honorary members shall be entitled to all of the privileges of sustaining members, except the right to vote and to hold office. They shall be nominated by the Board of Managers and shall be elected by four-fifths of the votes of the members present at any stated meeting of the Institute at which their nomination may be acted upon.

Section 7. Family privileges consist of the right to receive a card for each individual in the family of the member and resident with the member entitling the holder to unlimited free admission to the Museum and the Planetarium.

Section 8. Members belonging to classes of membership existing prior to the amendment of this ARTICLE shall be reclassified in a manner consistent with their former dues and privileges.

ARTICLE III.

PAYMENT OF DUES.

Section 1. The annual fees for membership shall be due and payable on the first day of each month, whichever is nearest to the date of election or as determined by the Board of Managers.

Section 2. Any member whose dues are more than two months in arrears shall have all the privileges of membership suspended until such time as all arrears are paid. Should the dues not be paid when they become six months in arrears the said member shall forfeit his membership.

Section 3. The Board may remit temporarily in whole or in part the dues of any member either by action in a particular case or by establishing regulations governing certain cases.

Section 4. Every person admitted to membership in the Institute shall be considered as liable for the payment of dues until he shall have resigned, been dropped or have been relieved therefrom by the Board of Managers.

Section 5. Resignations of memberships shall be made to the Board of Managers in

writing, but need not be accepted until all dues and arrears up to date of resignation shall have been paid.

Section 6. The privileges and title of Associate member may be obtained for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the Student or Associate Membership dues paid by the member during the preceding ten years, but in no case shall the deduction exceed $50.00.

Section 7. The privileges and title of Active Member shall be enjoyed for life or may be obtained for life by a member who has heretofore or who shall hereafter pay therefor, in one year, the sum of $300, except that a person residing permanently at a distance of twenty-five miles or more from Philadelphia may become an Active Member for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the dues paid by the member during the preceding ten years, but in no case shall the deduction exceed one-half of said payment. Associate Members for life may become Active Members for life by paying therefor in one year the sum of $200.

Section 8. Firms, corporations, associations or individuals may nominate and subscribe for the membership dues of groups of members of any class or classes, at the annual dues provided for, subject to the approval of the Board as to any particular nominee. If the dues of these nominees amount to $100 or more in the aggregate, the firm, corporation, association or individual shall be known as an Affiliate of the Institute.

ARTICLE IV.

ELECTION OF OFFICERS.

Section 1. The officers shall be a President, not more than five Vice-Presidents, a Secretary, an Assistant Secretary, a Treasurer, two Assistant Treasurers, a Controller, a Librarian, a Director of the Benjamin Franklin Memorial and The Franklin Institute Museum, a Manager of Operations of the Benjamin Franklin Memorial and The Franklin Institute Museum, a Board of twenty-four (24) Managers and such other Officers as the Board of Managers may elect or appoint.

Section 2. At the annual meeting of the Institute the President, the Vice-Presidents, and the Treasurer shall be elected to serve one year, and eight Managers shall be elected each year to serve for three years; provided, that the officers now elected, or who may hereafter be elected, shall continue to serve until their successors be elected.

Section 3. All elections of the Institute shall be by letter ballot and no vote may be cast by proxy.

Section 4. Nominations for President, Vice-Presidents, Treasurer and Managers shall be made in writing at the stated meeting in the month of December. Each nomination paper must be signed by at least two members, who shall certify that the candidate will serve if elected. After the nominations are closed, the President shall appoint three members, who are neither officers nor nominees, to act as tellers of election. The list of nominees shall be posted at the Institute and incorporated (with directions for voting) in a ballot to be sent to each member by the Secretary at least one week before the date of election. Each ballot shall be accompanied by a return envelope addressed "To the Tellers of Election," and provided with a space for the signature of the member voting.

Section 5. On the date of the annual meeting, and at an hour previously designated by their chairman, the tellers shall meet at the Institute, and shall count all legal votes that have been received by mail or placed in the ballot box before eight o'clock P.M.; and when the count is completed they shall report to the annual meeting of the Institute the total number of ballots cast, together with the number of votes received by each candidate. Thereupon the presiding officer shall announce the names of the candidates who received the plurality of votes, and shall declare them elected officers and Managers of the Institute for the ensuing terms.

Section 6. At the organization meeting of the Board of Managers, the Board of Managers shall elect such other officers provided for in Section 1 of ARTICLE IV; shall elect or appoint such other officers as it may determine upon, and shall determine and fix the compensation, if any, to be paid to the officers so elected or appointed by them. The officers who are in office immediately prior to the annual meeting shall continue in office until their successors are elected or appointed by the Board of Managers as herein provided.

Section 7. Vacancies occuring in any office may be filled by the Board of Managers by election or appointment of persons to serve until the next annual election.

ARTICLE V.

BOARD OF MANAGERS.

Section 1. The Board of Managers shall have general charge and control of the Institute and of the Benjamin Franklin Memorial and The Franklin Institute Museum, and shall consist of twenty-four members elected as provided in ARTICLE IV. The President, the Vice-Presidents, the Secretary, the Treasurer, the Chairman of the Committee on Science and the Arts, and the Chairman of the Library Committee shall be ex officio members. A quorum of the Board of Managers shall be nine of the elected and ex officio members. The Board of Managers may adopt such by-laws, rules and regulations for the governance of their affairs as are not inconsistent with the Charter and these By-Laws.

Section 2. They shall present, through the President, at the annual meeting of the Institute, a report of the condition of the affairs of the Institute.

Section 3. They shall hold stated meetings in each month except in July and August.

Section 4. Special meetings may be called by the President at his discretion and shall be called by him on written request of the Executive Committee or of any seven members of the Board. In case of his absence or refusal to act, such special meeting shall be called by the Secretary.

Section 5. Members who have not attended five regular meetings in the twelve months prior to the stated meeting of the Institute in December, shall be reported thereat as having resigned, unless it be unanimously voted by the Board at that meeting that such member has been absent for sufficient reason.

Section 6. All vacancies on the Board of Managers shall be filled by the Board until the next annual meeting of the Institute.

Section 7. The Board of Managers may elect an Executive Committee consisting of five of its Members with such authority to act on behalf of the Board as the Board may delegate.

ARTICLE VI.

DUTIES OF OFFICERS.

Section 1. The President shall be the executive head of the Institute and, under the supervision of the Board of Managers, shall have general charge of the affairs of the Institute. He shall preside at all meetings of the Institute and of the Board of Managers and shall be ex officio a member of all Committees.

Section 2. The Vice-Presidents shall exercise the duties of the President in his absence in the order of their seniority in office.

Section 3. The Secretary shall have general administrative supervision over all of the affairs of the Institute other than those matters specifically delegated by these By-Laws to the Executive Committee, Finance Committee, and Treasurer. He shall keep the minutes of all meetings of the Institute and of the Board of Managers, and shall perform all the duties usually pertaining to the office of Secretary. He shall prepare the annual budget, submit it to the Finance Committee for first approval, and to the Board of Managers for final approval. He shall be an ex officio member of all Committees. He shall report to the President. In the absence or disability of the Secretary, the Assistant Secretary shall perform his duties.

Section 4. The Director of the Benjamin Franklin Memorial and The Franklin Institute Museum shall have general administrative supervision over the Memorial and Museum, of the exhibits therein displayed, and of the activities centering in the Museum. He shall annually appoint the members of the scientific staff of the Museum, subject to the approval of the Secretary and of the Board of Managers. He may be appointed by the Board of Managers an ex officio member of any Committee. He shall report to the Secretary.

Section 5. The Treasurer shall have custody of all moneys received from the Committee on Finance, together with all moneys received by the Institute from dues, admissions and other incidental collections. He shall deposit in the name of the Institute, in such bank or banks as the Board of Managers may direct, all moneys in his custody. He shall disburse such moneys only upon vouchers certified by the Controller or, in the absence

or disability of the Controller, by the Auditor or the Secretary. He shall keep accurate accounts of the income and disbursements of the Institute, shall report current receipts and payments at each stated meeting of the Board of Managers, and shall make a detailed statment of the financial condition of the Institute at its annual meeting. He shall give bond to an amount, and with such surety, as theBoard of Managers shall determine. He shall report to the President. In the absence or disability of the Treasurer, the Assistant Treasurers shall, in the order of their seniority in office, perform his duties.

Section 6. The Controller shall keep the detailed accounts of the Institute, shall collect all moneys due the Institute and shall deposit them in the Treasurer's account. He shall approve all expenditures for payment. He shall act as the business agent of all publications of the Institute, except as the Board of Managers may specifically otherwise from time to time provide. He shall perform such other duties as are assigned to him by the Secretary. He shall report to the Secretary.

Section 7. The Librarian shall have immediate charge of the library and reading-room of the Institute. He shall report to the Secretary.

Section 8. The Manager of Operations of the Benjamin Franklin Memorial and The Franklin Institute Museum shall have immediate charge of the Benjamin Franklin Memorial and The Franklin Institute Museum. He shall have charge of the maintenance and care of all real estate properties of the Institute, and of its shops. He shall report to the Director of the Benjamin Franklin Memorial and The Franklin Institute Museum.

ARTICLE VII.

BOARD OF COUNCILLORS.

The Board of Councillors shall consist of not more than fifty members and shall embrace, as ex officio members, the Governor of Pennsylvania, the Chief Justice of the Supreme Court of Pennsylvania, the Mayor of the City of Philadelphia, the President of the City Council of Philadelphia, the President of the Board of Public Education and the Superintendent of Schools of the City of Philadelphia, the Provost and the President of the University of Pennsylvania, the President of Commissioners of Fairmount Park, the President of the American Philosophical Society, the President of the Poor Richard Club, and the President and Secretary of The Franklin Institute, which two latter shall respectively be Chairman and Secretary of the Board of Councillors. Additional members shall be nominated by the President or Secretary of the Institute and elected by the Board of Managers, at such intervals as the Board of Managers may see fit. The Board of Councillors shall meet at the call of its Chairman or of the Board of Managers for the consideration of any matter that pertains to the welfare of the Institute. The Secretary shall from time to time send to the members of the Board of Councillors a report of the activities and accomplishments of the Institute.

ARTICLE VIII.

COMMITTEES OF THE INSTITUTE.

Section 1. There shall be the following Standing Committees of the Institute:

1. Bartol Research Foundation Committee.
2. Biochemical Research Foundation Committee.
3. Committee on Science and the Arts.
4. Endowment Committee.
5. Finance Committee.
6. Library Committee.
7. Meetings Committee.
8. Membership Committee.
9. Memorial and Museum Committee.
10. Publicaions Committee.

Section 2. Each standing committee of the Institute shall consist of at least ten members, not more than five of whom shall be members of the Board of Managers, except that the Committee on Science and the Arts shall consist of sixty-six members, without limitation as to the number who may be members of the Board of Managers, and except that the Bartol Research Foundation Committee shall consist of twelve members as provided for in Section 7 of this ARTICLE.

Section 3. The members of each committee shall serve one year, except that members of the Committee on Science and the Arts shall serve three years.

Section 4. The members of each committee, other than ex officio members specifically provided for by these By-Laws, shall be appointed by the President and approved by the Board of Managers at the organization meeting of the Board following the annual meeting, except that each year but twenty-two members of the Committee on Science and the Arts shall be so appointed and approved.

Section 5. The Chairman of each committee shall be designated by the President, except that the Library Committee and the Committee on Science and the Arts shall select their chairmen. A chairman who is not an elected or ex officio member of the Board of Managers shall have the privilege of the floor at meetings of the Board but shall not have the right to vote.

Section 6. Each committee shall report monthly through its Chairman or through the Secretary, as it may elect, to the Board of Managers.

Section 7. The Bartol Research Foundation Committee shall consist of twelve members, including the President and the Secretary of the Institute and the Director of the Bartol Research Foundation as ex officio members and nine members of the Institute of whom not more than four shall be members of the Board of Managers. The Committee shall, after consultation with the Director of the Bartol Research Foundation and subject to the approval of the Board of Managers, collaborate with the Secretary in carrying out the purposes and determining the policies of the Bartol Research Foundation. It shall appoint the Director and the Staff of the Laboratories, subject to the approval of the Board of Managers. The Director of the Bartol Research Foundation, to whom all other employees of the Foundation shall report, shall have charge of the scientific activities of the Foundation and shall report on all matters to the Committee or to the Secretary, as the Committee may elect.

Section 8. The Biochemical Research Foundation Committee shall report to the Board of Managers from time to time on the condition of the affairs and operation of said Foundation and shall be available to the Director of the Biochemical Research Foundation and its Advisory Council for collaboration and advice.

Section 9. The Committee on Science and the Arts shall investigate current discoveries, inventions and other achievements in the sciences and their application in the mechanical and industrial arts with a view of affording such recognitions as lie within the power of the Institute to bestow. The Committee shall exercise independent judgment therein. In all matters of a general or administrative nature the Committee shall collaborate with the Secretary.

Section 10. The Endowment Committee shall, in collaboration with the Secretary, encourage the gift of funds to the Institute.

Section 11. The Finance Committee shall have charge and supervision of all securities and general funds of the Institute including any funds derived from bequests and endowments. It shall invest all general funds available for investment. It shall pay the income from all investments to the Treasurer of the Institute. It shall approve the annual budget as to form and expected income from invested funds before it is presented to the Board for final approval, and shall thereafter make such examinations of financial results of operations as will insure compliance with the annual budget. It may, with the approval of the Board of Managers, appoint a Trust Company of the City of Philadelphia to act as Fiscal Agent under the direction of the Committee.

Section 12. The Library Committee shall have charge of the library and, in collaboration with the Secretary, purchase books and publications suitable to and consonant with the purposes of the library of the Institute.

Section 13. The Meetings Committee shall in collaboration with the Secretary, secure for presentation before the Institute papers dealing authoritatively with subjects of import in the fields of science, engineering and industry.

Section 14. The Membership Committee shall, in collaboration with the Secretary, promote the several memberships defined in ARTICLE II of these By-Laws.

Section 15. The Memorial and Museum Committee shall, in collaboration with the Secretary, be of counsel and advice to the Director of the Benjamin Franklin Memorial and The Franklin Institute Museum, and with the scientific staff of the Museum concerning the activities and the exhibits of both the Memorial and the Museum.

Section 16. The Publications Committee, in collaboration with the Secretary, shall have charge of all publications of the Institute other than publications of the Bartol Research Foundation.

Section 17. Each committee shall organize and adopt rules as it sees fit, subject to the provisions of these By-Laws and the approval of the Board of Managers.

ARTICLE IX.

MEETING.

Section 1. The Institute shall hold stated meetings on the third Wednesday of each month except in June, July, August and September, at 8:30 P.M.

Section 2. Special meetings shall be called by the President upon the order of the Board of Managers or within ten days upon the written application of twenty-four voting members of the Institute.

Section 3. Twenty-four members shall constitute a quorum at any stated or special meeting.

Section 4. The Annual Meeting of the Institute shall be held on the third Wednesday of January of each year at 8:30 P.M. Elections at Annual Meetings shall not result from the poll of less than forty-eight ballots cast in accordance with ARTICLE IV, Section 5, of these By-Laws.

ARTICLE X.

AMENDMENTS.

These By-Laws may be altered or amended at any stated meeting of the members of the Institute, provided notice in writing, signed by two members, of the proposed alteration or amendment, shall be given to the Board of Managers two months prior to the said meeting, except that amendments to ARTICLE I, relating to capital stock, must be ratified subsequently by a majority of the stock represented at a meeting specially called for this purpose.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 8, 1947.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 8, 1947.

DR. HIRAM S. LUKENS *in the Chair.*

The following reports were presented for final action:

No. 3173
No. 3174 } Franklin Medal.

This report recommended the award of two Franklin Medals; one to ENRICO FERMI, of Chicago, Illinois, "In recognition of his brilliant contributions to both theoretical and experimental physics, and of his skill in combining theory with experiment so as to open up a vast new field of research in which practical use may be made of the energy stored in the nuclei of certain kinds of very heavy atoms"; and one to

ROBERT ROBINSON, of Oxford, England, "In recognition of his numerous and brilliant researches in organic chemistry, particularly, his invaluable contributions to the knowledge of natural substances, and of his superb experimental skill in organic synthesis."

No. 3176: Clamer Medal.

This report recommended the award of a Francis J. Clamer Medal to EDGAR H. DIX, JR., of New Kensington, Pennsylvania, "In consideration of his meritorious contribution to the development of high strength corrosion-resistant aluminum products."

No. 3128: Metal Locator for Use in Surgery.

This report recommended the award of an Edward Longstreth Medal to SAMUEL BERMAN, of New York, New York, "In consideration of the development of a Metal Locator for use in surgery which device has greatly facilitated the location and removal of foreign metallic bodies imbedded in the tissues."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M., Wednesdays and Thursdays from 2 P.M. until 10 P.M.

RECENT ADDITIONS.

AERONAUTICS.

ADLER, HERMAN. Wie Werde ich Offizer der Luftwaffe. 1943.

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FORELL, FRITZ VON. MÖLDER UND SEINE MÄNNER. 1941.

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BRANDENBERGER, E. Röntenographisch-Analytische Chemie. 1945.
DEBELL, J. M., W. C. GOGGIN AND W. E. GLOOR, German Plastic Practice. 1946.
Organic Syntheses. Volume 26. 1946.
PORTER, JOHN ROGER. Bacterial Chemistry and Physiology. 1946.
ROGERS, ALLEN, Rogers' Industrial Chemistry. Volumes 1 and 2. 1946.
Society of Dyers and Colourists. Fibrous Proteins. 1946.
WATERS, W. A. The Chemistry of Free Radicals. 1946.

DICTIONARIES.

EITZEN, KURT HILMAR. Deutsch-Englisches: Englisch-Deutsches Militar-Worterbuch. 1943.

ELECTRICAL ENGINEERING.

SKRODER, C. E., AND M. S. HELM. Circuit Analysis by Laboratory Methods. 1946.

ENGINEERING.

Electronic Engineering Master Index. January 1935 to June 1945. 1946.
HETENYI, MIKTOS IMRE. Beams on Elastic Foundation. 1946.
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VANDERWALKER, F. N., ed. Drake's Cyclopedia of Painting and Decorating. 1945,

MATHEMATICS.

HOGBEN, LANCELOT. An Introduction to Mathematical Genetics. 1946.
LANDAU, EDMUND G. H. Vorlesgungen über Zahlentheorie. 1946.

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American Society for Metals. A. S. M. Review of Metal Literature. Volume 2. 1946.
PARKER, CHARLES M. The Metallurgy of Quality Steels. 1946.

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GUDERIAN, HEINZ. Die Panzertruppen. 1943.

NAVAL ARCHITECTURE.

WOOLER, RICHARD G. Tankerman's Handbook. 1946.

OPTICS.

LUCKIESH, MATHEW. Applications of Germicidal, Erythemal and Infrared Energy. 1946.

PHARMACY AND HYGIENE.

American Pharamaceutical Association. National Formulary. Eighth Edition. 1946.
HAVINGA, E., AND OTHERS. Modern Development of Chemotherapy. 1946.
HOPPE, HEINZ A. Drogenkunde. 1944.

PHYSICS.

RAO, V. V. I. The Decibel Notation. 1946.
SCHELVEN, THEODORE VAN. Weiss Magnetons as Components of Nuclear and Subnuclear Structures. 1945.
SMITH, EDWARD S. C., AND OTHERS. Applied Atomic Power. 1946.
SWANN, WILLIAM F. G. The Nature of Cosmic Rays. 1945.

RAILROADS.

Association of American Railroads. Carbuilders' Cyclopedia. 1946.

SUGAR.

GILMORE, A. B., ed. Porto Rico Sugar Manual. 1946.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Blood Picture of Normal Laboratory Animals.* A Review of the Literature 1936–1946.—MARY VIRGINIA GARDNER.

THE MOUSE

Not much information is available on the blood of normal mice, since these animals have been used very little in hematological work.

Method of Obtaining Blood. Blood is usually obtained by incising the tail vein or by puncturing the heart. Repeated use of either method over a short period of time results in anemia, since removal of even the small samples of blood needed in routine blood counts quickly depletes the small blood volume of the mouse. The erythrocyte count and the differential leukocyte count of blood from the tail differ little from those of blood from the heart, but the total leukocyte counts from the two sources differ widely. The average total leukocyte count for 8 normal mice was found by Fekete (1) to be 21,510 cells per cmm. in tail blood and 3,717 cells per cmm. in ventricle blood.

Red Blood Cells. The erythrocyte of the adult mouse is described by Fekete (1) as a non-nucleated, flexible, circular biconcave disc. The average number of red blood cells in the blood of the adult mouse ranges from 5,500,000 to 13,900,000 with an average of 9,229,000 per cmm. (Table I). No values were found for immature mice.

Kamenoff (6) found no significant difference between strains in the red blood cell counts, while both Fekete (1) and Gowen and Calhoun (4) reported differences as high as 2½ or 3 million erythrocytes per cmm. among the strains they studied. Fekete (1) found that male mice, regardless of strain, had slightly higher erythrocyte counts than did female mice, but Gowen and Calhoun (4) did not believe that the difference was statistically significant.

No values were found for erythrocyte diameter in mature mice, but Guzman and Briones (8) have reported the variations in red cell size to be found in mice within 24 hours after birth. They found that 40.8 per cent. of the erythrocytes averaged 8.32 μ or more in diameter, 34.8 per cent. ranged from 7.04 to 8.32 μ, 24.5 per cent. were 5.12 to 7.04 μ, and 1.9 per cent. were between 2.56 and 4.48 μ.

Hemoglobin. The hemoglobin content of the blood of the adult mouse ranges from 12.0 to 17.1 grams, with an average of 15.05 grams per 100 cc. of blood (Table II). Goulden and Warren (10) reported significantly higher hemoglobin values for females than for males in both cancer-resistant and cancer-susceptible strains. Both Goulden

* Continued from page 77, Vol. 243, No. 1.

TABLE I.

Erythrocytes.

Age of Mice	No. and Sex	Strain	♀ Erythrocytes × 10^6/cmm.		Reported by
			Average	Range	
Not given	39	CBA (Strong)	9.05		Dougherty (2)
Not given	13 M	C_{57} brown	9.704		Fekete (1)
Not given	4 F	C_{57} brown	9.58		Fekete (1)
Not given	6 M	C_{57} black	9.292		Fekete (1)
Not given	7 F	C_{57} black	8.5274		Fekete (1)
Not given	3 M	MacDowell-Bagg	10.426		Fekete (1)
Not given	8 F	MacDowell-Bagg	9.7335		Fekete (1)
Not given	10 M	dba	11.234	7.6–13.2	Fekete (1)
Not given	10 M	C_3H	8.841		Fekete (1)
Not given	5 F	C_3H	8.606		Fekete (1)
Not given	8 M	Leaden	11.096	9.4–13.9	Fekete (1)
Not given	8 F	Leaden	10.214	7.3–13.1	Fekete (1)
Not given	73	—		5.5–11.5	Feldt (3)
Not given	38	Bagg albino	6.95		Gowen (4)
Not given	41	Silver	8.78		Gowen (4)
Not given	45	Ervin	9.37		Gowen (4)
Not given	42	Swiss	7.43		Gowen (4)
Not given	41	Rockefeller Inst.	8.14		Gowen (4)
Not given	45	selected	9.32		Gowen (4)
6–8 weeks	65 M + F	albino	9.97		Jacobson (5)
Not given	44 M	—	10.0194		Kamenoff (6)
Not given	74 F	—	9.225		Kamenoff (6)
Not given	18	Swiss	8.93		Lin (7)
Average			9.229		

and Warren (10) and Strong and Francis (11) found that a cancer-resistant strain (CBA) had higher hemoglobin levels at all ages than did cancer-susceptible strains (R III and A). Francis and Strong (9) reported a gradual loss of blood pigment associated with age, and this was supported by Goulden and Warren (10) and Strong and Francis (11).

Platelets. The platelets of mouse blood appear in stained smears as numberous small, blue bodies. Copley and Robb (13) found an average of 278,240 platelets per cmm. in 9 mice studied, and, later (14), a range of 246,000 to 339,000 in 25 normal mice. Jacobson (5) found an average of 987,000 platelets per cmm. in 65 normal male and female mice from 6 to 8 weeks of age.

White Blood Cells. The most numerous of the leukocytes of adult mouse blood are the lymphocytes. According to Fekete (1) the mouse lymphocyte is large and spherical with an eccentric, slightly idented nucleus which almost fills the cell. The nucleus, in Wright-stained preparations, is very dark, while the cytoplasm is homogeneous and slightly basophilic. The monocyte, the largest cell in the blood of the normal adult mouse, has an eccentric, ovoid or bean-shaped, light-staining nucleus which is sometimes deeply indented. The cytoplasm is abundant, non-granular and slightly basophilic. The granulocytes

TABLE II.

Hemoglobin.

Age of Mice	No. and Sex	Strain	Hemoglobin g./100 cc.		Method	Reported by
			Average	Range		
Adult	39	CBA (Strong)	15.3		Alkaline hematin	Dougherty (2)
40 days	30 virgin F	CBA (Strong)	16.0		Acid hematin	Francis (9)
80–200 days	42 virgin F	CBA (Strong)	16.95		Acid hematin	Francis (9)
120–160 days	24 breeder F	CBA (Strong)	16.05		Acid hematin	Francis (9)
200 days	37 breeder F	CBA (Strong)	16.3		Acid hematin	Francis (9)
240–280 days	39 virgin F	CBA (Strong)	15.55		Acid hematin	Francis (9)
240–360 days	218 breeder F	CBA (Strong)	15.8		Acid hematin	Francis (9)
320–440 days	28 virgin F	CBA (Strong)	14.76		Acid hematin	Francis (9)
400–480 days	148 breeder F	CBA (Strong)	14.9		Acid hematin	Francis (9)
480 days	3 virgin F	CBA (Strong)	13.9		Acid hematin	Francis (9)
520–560 days	78 breeder F	CBA (Strong)	14.5		Acid hematin	Francis (9)
600–720 days	91 breeder F	CBA (Strong)	13.9		Acid hematin	Francis (9)
760–920 days	18 breeder F	CBA (Strong)	13.4		Acid hematin	Francis (9)
0–400 days	18 M	CBA (Strong)	15.9		Oxy-hemoglobin	Goulden (10)
0–400 days	55 F	CBA (Strong)	16.7		Oxy-hemoglobin	Goulden (10)
0–400 days	59 M	R III	13.45		Oxy-hemoglobin	Goulden (10)
0–400 days	50 F	R III	16.4		Oxy-hemoglobin	Goulden (10)
400–600 days	41 M	CBA (Strong)	15.5		Oxy-hemoglobin	Goulden (10)
400–600 days	50 F	CBA (Strong)	16.5		Oxy-hemoglobin	Goulden (10)
400–600 days	32 M	R III	13.35		Oxy-hemoglobin	Goulden (10)
400–600 days	42 F	R III	14.7		Oxy-hemoglobin	Goulden (10)
600–900 days	43 M	CBA (Strong)	14.8		Oxy-hemoglobin	Goulden (10)
600–900 days	31 F	CBA (Strong)	16.0		Oxy-hemoglobin	Goulden (10)
6–8 weeks	65 M + F	albino	14.35		(Photoelectric)	Jacobson (5)
120 days	30 F	A	17.1		—	Strong (11)
120–360 days	279 F	CBA (Strong	15.95		—	Strong (11)
160–280 days	242 F	A	15.69		—	Strong (11)
320–440 days	176 F	A	13.7		—	Strong (11)
400–440 days	115 F	CBA (Strong)	15.1		—	Strong (11)
480–640 days	67 F	A	11.96		—	Strong (11)
480–640 days	173 F	CBA (Strong)	14.38		—	Strong (11)
400–440 days	76	A	13.4		Acid hematin	Strong (12)
400–440 days	73	CBA (Strong)	14.45		Acid hematin	Strong (12)
Average			15.05			

are larger than the lymphocytes and their nuclei are varied in shape, appearing as rings or constricted into lobes. The cytoplasmic granules of the neutrophils stain faintly.

The average number of the different leukocytes, expressed as the number per 100 white cells, is:

Neutrophils.....20.62 (8.0–57.9)
Eosinophils..... 2.58 (0.0–15.1)
Basophils.....rare
Lymphocytes.....66.56 (36.2–89.8)
Monocytes..... 5.73 (0.7–14.0)

The average total number of leukocytes in the blood of the adult mouse is 14,080, regardless of sex or strain. The figures given in Table III represent the reported values for peripheral blood. Since Fekete (1) reported levels for heart blood and not for tail blood, his values are

TABLE III.
Leukocytes.

Age of Mice	No. and Sex of Mice	Strain	Leukocytes per cmm.		Cells per 100 Leukocytes						Reported by
			Average	Range	Neut.	Eo.	Baso.	Lymph.	Mono.	Other	
Not given	99	CBA (Strong)	12,814		25.4			74.8			Dougherty (2)
Not given	17 M + F	C_{57} brown			14	3.0		71	12		Fekete (1)
Not given	13 M + F	C_{57} black			22	0.6		66	11		Fekete (1)
Not given	11 M + F	MacDowell-Bagg			23	0.3		63	13		Fekete (1)
Not given	10 M	dba			25	0.4		64	11		Fekete (1)
Not given	15 M + F	C_3H			23	0.2		63	14		Fekete (1)
Not given	8 M	Leaden			9	3.0		79	8		Fekete (1)
Not given	8 F	Leaden			8	4.0		80	9		Fekete (1)
Not given	8 F + M	—	21,510	16,350–32,460							Fekete (1)
Not given	—	—	—	—	10–40	0–4		35–90	0–3		Feldt (3)
Not given	38 M + F	Bagg albino	11,100		18.2	2.05		65.1	1.15	13.6	Gowen (4)
Not given	41 M + F	Silver	11,600		14.2	0.93		74.1	1.31	9.4	Gowen (4)
Not given	45 M + F	Ervin	14,600		14.0	3.76		69.4	2.58	10.3	Gowen (4)
Not given	42 M + F	Swiss	16,100		9.4	1.93		75.3	1.21	12.0	Gowen (4)
Not given	41 M + F	Rockefeller Inst.	22,500		13.6	2.10		67.3	0.67	16.4	Gowen (4)
Not given	45 M + F	selected	19,600		15.0	1.98		72.8	0.71	10.4	Gowen (4)
Not given	115 M	—	15,600		15.3	2.07		68.7	1.41	12.7	Gowen (4)
Not given	133 F	—	15,400		12.7	2.04		72.7	1.16	11.4	Gowen (4)
Not given	39	C_3H	11,550	7,850–15,820	38.5			58.8			Henshaw (15)
Not given	—	LAF_1	7,800		15.3			80.7			Henshaw (15)
6–8 weeks	65 M + F	albino	8,420		25.1	2.5	1	65.5	6.5		Jacobson (5)
Not given	18	Swiss	10,100		57.9	15.1	0	36.16	8		Lin (7)
Not given	2	—	14,980		18.7	2.3		75	4.7	0.44	Parsons (16)
Not given	10	—		7,000–20,000	17.8	0.8		89.8	1.6		Schäfer (17)
Adult	M	C_3H	11,550	7,850–15,820	39.3			58.8			Nettleship (18)
Average			14,080		20.62	2.58		66.56	5.73		

not included in the table. Gowen and Calhoun (4) found that the white blood cell count of mice increases with age. They showed also that there is a significant difference in the number of leukocytes in animals of different strains, but not in animals of different sex.

Bleeding Time. Copley and Robb (14) found the bleeding time for 3 normal mice to range from 32 to 48 seconds.

Sedimentation Rate. No values were found in the literature.

Specific Gravity. Dougherty and White (2) found the specific gravity of whole blood in 19 mice of the CBA (Strong) strain to average 1.060.

Resistance of Red Blood Cells. No values were found in the literature.

Hematocrit. No values were found in the literature.

Blood Volume. Oakley and Warrack (19) found the average blood volume of 46 normal male mice to be 63.5 cc. per kg., and that of 54 normal females to be 62.9 cc. per kg. The average blood volume of 20 female mice at different stages of pregnancy was 74.6 cc. per kg. (weight of mothers less weight of fetuses). The increased blood volume in pregnant females persisted for as many as 10 days post-partum.

The values recorded here for red blood cell count, hemoglobin content and differential leukocyte count are not significantly different from those compiled by Scarborough (20). The total leukocyte counts recorded here are somewhat higher on the average than those given by Scarborough.

Values are given for specific gravity, bleeding time and platelet count; these were not included in Scarborough's review.

(*To be continued*)

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BOOK REVIEWS.

THE ALKALINE-EARTH AND HEAVY-METAL SOAPS, by Stanley B. Elliott. 342 pages, illustrations, 15 × 23 cms. New York Reinhold Publishing Corporation, 1946. Price $7.50.

Metallic soaps are the alkali, alkaline-earth, or heavy-metal salts of monobasic, complex organic acids. The two clearly defined classes are those which show pronounced water solubility and those which show water insolubility. The subject of this book, although insoluble in water, shows marked solubility or solvation in non-polar solvents. Numerous brief discussions of these compounds have appeared at various times in journals, and it is the purpose here to give a more lengthy discussion on the manufacture, properties and typical applications of them.

In the very beginning the constitution of metallic soaps is taken up including organic and inorganic raw materials, solvents and addition agents. Further space is devoted to each of the subjects of precipitated and fused soaps, which gives up to this point, a good knowledge of types of soap and the various methods of production. There follows then a study of the layout of a soap plant and the types of equipment used in processing.

The presentation of the Applications of Metallic Soaps is made in an attempt to simplify the classification of uses, with the goal constantly in view of a wider and more intelligent use of soaps. The properties on which this discussion is based are (1) the physical characteristics of the soap, (2) the ability of the soap to influence the characteristics of liquids in which it is dispersed, and (3) the ability of the soap to dissolve in certain organic solvents and supply metal cations. Following this, there are eight chapters in which soaps of each of the eight groups of metals are considered, and a final chapter dealing with analysis of matallic soaps and raw materials used in their manufacture. The last part of the book contains appendices giving patents, specifications, applications, etc. There is a glossary and author and subject indices.

The work is one well suited to be placed with other American Chemical Society Monographs. It makes needed information readily avalable, and it contributes to a better understanding.

R. H. OPPERMANN.

SMITH'S COLLEGE CHEMISTRY, by Wm. F. Ehret. Sixth Edition. 677 pages, illustrations, 18 × 25 cms. New York, D. Appleton-Century Co., 1946. Price $4.75.

The title of this book rings with familiarity to many chemists, physicists, and engineers. Previous editions have been widely used as texts in many schools, in fact the first issue of Smith's Inorganic Chemistry in 1906 inaugurated a revolution in methods of instruction in America, in which there was a clear and logical presentation of the fundamentals of the science. Not only have Smith's volumes enjoyed phenomenal popularity in this country and in Great Britain but in other countries as well through translations of the work. Alexander Smith died in 1922 after the first and second editions of College Chemistry were published. The next three editions had his colleague James Kendall as their author, and the present sixth edition by William F. Ehret is a revision by one who has come under the tutelage of a number of Smith's disciples including Kendall.

The work has undergone considerable recasting although the sequence of topics remains similar to that of previous editions, covering inorganic chemistry with emphasis and giving adequate attention to organic, physical and analytical chemistry. There are a number of noteworthy changes in the contents of the chapters. The rudiments of atomic structure have been introduced in the fourth chapter which is really the first, after a conception is given of the general chemical basis of matter. The relative sizes of atoms and ions are explained in indicating the differences in activity and basicity of the several elements. The section on crystal structure has been largely rewritten and now appears later in the text incorporated in a chapter on salt and sodium hydroxide. The series of chapters on the periodical system, transmutation

of elements, atomic numbers, and atomic structure which formerly began in about the middle of the text has been almost completely rewritten and now precedes the series of chapters dealing with electrolytic solution phenomena. The latter have also been changed to bring them into line with a modern approach to the subject. The latter portion of the book dealing with metals has been made consistant with recent knowledge. In each chapter the important physical and chemical properties of the metals are summarized in tabular form.

There are 52 chapters in all and with an appendix containing helpful tabular information. At the end is a subject index. The work is truly one worthy to bear the name of Smith's College Chemistry.

R. H. OPPERMANN.

HANDBOOK OF CHEMISTRY, compiled and edited by Norbert Adolph Lange. 2082 pages, 13 × 20 cms. Sandusky, Handbook Publishers, Inc., 1946. Price $7.00.

This is the sixth edition of a well known and useful work. The material it contains is revised and changed but the size of this one volume handbook remains about the same as the previous edition. Perhaps the most important change in this edition is the completely revised and enlarged table of physical constants of inorganic compounds. This table has been increased to include 2603 compounds with a corresponding list of more than 1300 synonyms. For the first time, wherever possible, data on the refractive index have been included in this table. Other tables have been revised and others added, including Heat and Free Energy of Formation of Compounds, Ionization Constants of Acids and Bases, Electromotive Series of Metals and Alloys, Critical Constants of Gases, Factors for Reducing Gas Volumes to Normal Temperature and Pressure, True Capacity of Glass Vessels.

R. H. OPPERMANN.

BEAMS ON ELASTIC FOUNDATION, by M. Hetenyi. 255 pages, illustrations, 18 × 26 cms. Ann Arbor, The University of Michigan Press, 1946. Price $4.50.

There are many developments of interest to research workers and engineers about which little if anything has been published, with regard to beams on elastic foundation where the pressure in the foundation is proportional at every point to the deflection of the beam at that point and independent of the pressure or deflection occurring in other parts of the foundation. This book is presented as a mathematical analysis covering various forms of the elastically supported beam and including the development of new solutions and new cases of loading, material which has not been published before. The work starts with general solutions of the elastic line where two different methods are presented, both aiming to determine the integration constants from prescribed end conditions of the elastic line. It is shown that the main difficulty in applying the general solution to particular problems arises in the determination of the integration constants which involved a considerable amount of work. The method of superposition is suggested as a means of avoiding these difficulties. The advantage lies in the fact that the determination of the integration constants for a beam of unlimited length (an infinitely long beam) is very simple and that the equation of the deflection line for any loading can be obtained in a concise form. This treatment leads into the derivation of such deflection formulas and the demonstration that by superposing the formulas obtained for the infinitely long beam, solutions can be derived for beams of any length and with any loading and end conditions. This is followed by listing ready formulas for a number of simple cases of loading on beams of finite length, derived by the method of superposition.

Subsequent topics are beams of variable flexural rigidity and variable modulus of foundation, straight bars under simultaneous axial and transverse loading, elastic stability of straight bars, torsion of bars, circular arches, and finally continuity in the foundation. The last topic, involving cases in which the supporting body is an elastic continuum, includes a discussion of foundation layers. The work is rigorous, comprehensive and complete.

R. H. OPPERMANN.

APPLICATIONS OF GERMICIDAL, ERYTHEMAL AND INFRARED ENERGY, by Matthew Luckiesh. 463 pages, drawings and illustrations, 14 × 21 cms. New York, D. Van Nostrand Company, Inc., 1946. Price $5.50.

During recent years many new sources of ultraviolet, visible and infrared radiant energy have been developed. These, combined with methods of measurement, have added greatly to the possibilities of control of dosage and particularly to knowledge, for meaningful measurements provide the foundation of any science or practice. Notwithstanding these contributions, there are many uncertain regions and even gaps in the knowledge of the subject. Much of the uncertainty is directly traceable to meager knowledge of physics on the part of those who use these physical agencies. The value of much published material is greatly reduced by the absence of accurate measurements and adequate identification of the spectral distribution of energy. The present work aims to supply the basic foundation of measurements of radiant energy of various wavelengths and their effectiveness in certain major ways. Such a foundation is of importance in an increasing variety of research and practice.

The opening chapter is general, discussing various spectral regions and present artificial sources of radiant energy. Radiant energy from the sun is next examined with the ultraviolet component of solar energy and the erythemal effectiveness of skylight with a very interesting summarization for each hour daily for a period of six years by means of an automatic recording device. Succeeding chapters deal with erythema and tan, units and terminology for biological effectiveness, germicidal energy, disinfecting controlled air, infected communal air, disinfecting air in occupied interiors and disinfecting water. In a discussion on artificial sunlight, the sun lamp is mentioned with the properties it should have. It is shown that the term "artificial sunlight" is not fixed in meaning. Strictly it means artificial radiant energy of the same intensity and spectral character as natural sunlight. In practice, it usually applies adequate ultraviolet energy from λ2900 to λ3600 as determined by erythermal and antirachitic effectiveness. By extension it should include sources which also emit ultraviolet energy of shorter wavelengths than exists in natural sunlight, provided an overall effect of such a source is comparable to that of the sun.

The fading of materials is the subject of a separate chapter as are ultraviolet energy and plant life, radiant energy in common illuminants, reflection and transmission, measurement of ultraviolet energy, and various applications of radiant energy which furnishes additional aid by giving brief discussions of some specific uses which promise to become extensive. These include the sterilizing of highly absorbing materials, disinfecting air for industrial processes, sterile storage, extensive uses of fluorescence, and the so-called light-bath as a contrast to the hot, dry and humid rooms of the turkish bath. At the end of the book 124 references are listed, and there is a subject index.

There is a fund of information in the 440 pages of text in this book. It is well presented, reasonably and logically, and is supplemented with helpful photographs, drawings and curves. The work is a contribution toward present and future applications bound to be extensive.

R. H. OPPERMANN.

THE ELECTRONIC ENGINEERING MASTER INDEX, 1935–1945, edited by Frank A. Petraglia. 209 pages, 18 × 26 cms. New York, The MacMillan Company, 1946. Price $6.00.

This book of 209 pages is an index of articles in electronic engineering and allied periodicals between 1935 and 1945. A total of 65 periodicals is covered. It contains a list of approximately 10,000 entries. The indexing system employed is one of electronic subject headings alphabetically arranged and cross indexed, the cross indexing appearing in the back of the book. A goodly number of subject headings has been chosen, some of which are given subheadings such as Noise, Noise Elimination, Noise Measurements. Others are compound such as Oscillation, Oscillators and then there are groupings including Audio, Barkhausen-Kurz, Beat-Frequency, etc. The next heading after Oscillators U.H.F. is the compound subject heading Oscillograph, Cathode-Ray which is followed again by Oscillators with the subheading Frequency Stability of—somewhat out of alphabetical order but none the less valuable because

the groupings are small and quickly seen by the literature searcher. Each entry gives the full title of article or text, author's name, periodical, and date of issue.

The value of any index is only determined through use. A fair trial is suggested for this one.

R. .H. OPPERMANN

FORENSIC CHEMISTRY AND SCIENTIFIC CRIMINAL INVESTIGATION, by A. Lucas. 340 pages, tables, 14 × 22 cms. London, Edward Arnold & Co., 1945. Available also from Longmans Green & Co., New York. Price $7.00.

Originally published in 1921 this book on the application of chemistry "to the solution of certain problems that arise in connection with the administration of justice" now appears in a fourth edition. It has been brought up to date with numerous alterations and additions throughout the text. Many of the changes are the result of new cases which the war brought to the author's attention and whose most interesting points have been incorporated into the text in the appropriate places.

The main outline of the volume has not been changed and covers a wide variety of topics. Emphasis is placed on documents, poisons and firearms, but numerous other topics such as counterfeit coins, blood stains, explosives, robbery from letters and parcels, and tobacco are discussed. An introduction points out general procedure to be followed in the reception of articles for examination, their subsequent study and the communication of results.

The treatment is comprehensive covering different methods of examination, with details of things for which to watch. As an example in discussing paper, under the general subject of documents, the author shows the importance of the composition of the paper, water-marks, discoloration, folds and tears, any of which may prove a deciding factor. Examples are cited in the text and most chapters end with a section of illustrative cases.

Some 200 additional references augment the valuable bibliographical features of the book. This revision will enable the volume to maintain the reputation as a standard work in its field which is has enjoyed for a quarter of a century.

GEO. E. PETTENGILL.

THE PATH OF SCIENCE, by C. E. Kenneth Mees, with the cooperation of John R. Baker. 250 pages, illustrations, 15 × 22 cms. New York, John Wiley and Sons, 1946. Price $3.00.

This book is an expansion of the Hitchcock professorship lectures at the University of California in 1943. It is more ambitious than its modest title suggests, forming a commentary upon the science of history and the history of science. For since the avowed purpose of the author is to trace "the development of science and its relation to the history of science," if we are to understand the impact of science on society it is essential to know what are the points of impact.

Drawing upon an extradordinarily wide range of reading, the author first examines history in much the same manner as he would conduct a laboratory experiment His object is to ascertain whether there is any orderliness in the arrangement of its events. Dr. Mees finds a satisfactory pattern to the progress of civilization in its resemblance to a helix. The coils lie closely piled when they represent the centuries leading up to the fruitful seventeenth century. After this, when the scientific method has been introduced there is a sudden swift up-surge in the helix representing the more rapid rate of scientific achievement. Thereafter, the coils have a wider vertical extension.

In his chapters on the growth of ideas, Dr. Mees is operating on his own territory. An industrial research worker of no mean repute, he deals with the tasks of men whom he thoroughly understands. The great scientists are his characters whom he pictures against the background of their times, and the greatest of them against the background of all times. The result, in a volume of this size, can only be impressionistic, but the author never allows any character to dominate the scene, so that the impression he conveys is good. Where he does not achieve his effect with a deft flick of his own prose, he always has an appropriate quotation ready for application.

The author has scant time to peer into the future, but he methodically treats of our present condition of science and its organization in the light of the lessons from the past. When results descend upon us at the rate they have descended during the past hundred years, we become bewildered, our standards are blurred, and our perceptions are blunted. Dr. Mees contrives to keep his picture clear. It is no pretentious piece of counterfeit scholarship, but a clean cut working-day analysis. In recalling the vast progress that has been made, he concludes that the time has come when we should take stock of our achievements and pause to digest the experience, so that we may find out where it is leading us. Perhaps the extinction of some types of man may not be too high a price to pay for the evolution of another type, one more rational than we, a type that sets a higher prize on the spirit than it does on the fission of uranium.

T. C.

PUBLICATIONS RECEIVED.

Petroleum Production, by Park J. Jones. Vol. II, 293 pages, diagrams, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1946. Price $4.50.

Butalastic Polymers, by Frederick Marchionna. 642 pages, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1946. Price $8.50.

Advanced Mechanics of Materials, by Glenn Murphy. First Edition. 307 pages, illustrations, 15 × 24 cms. New York, McGraw-Hill Book Company, 1946. Price $4.00.

Explosion and Combustion Processes in Gases, by Wilhelm Jost. First Edition. 621 pages, illustrations, 16 × 24 cms. New York, McGraw-Hill Book Company, 1946. Price $7.50.

Microcalorimetry, by W. Swietoslawski. 199 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1946. Price $4.75.

Galvanizing Handbook, by John R. Daesen. 166 pages, illustrations, 18 × 25 cms. New York, Reinhold Publishing Corporation, 1946. Price $5.25.

Heating and Air Conditioning, by John R. Allen, James Helbert Walker and John William James. Sixth Edition. 667 pages, illustrations, plates, 16 × 23 cms. New York, McGraw-Hill Book Company, 1946. Price $5.50.

A Textbook of Qualitative Analysis, by Wm. Buell Meldrum and Albert Frederick Daggett. 431 pages, drawings, 14 × 22 cms. New York, American Book Company, 1946. Price $3.50.

Science Remakes Our World, by James Stokley. 318 pages, illustrations, 15 × 22 cms. New York, Ives Washburn, 1946. Price $3.50.

The Path of Science, by C. E. Kenneth Mees. 250 pages, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1946. Price $3.00.

Man Does Not Stand Alone, by A. Cressy Morrison. Revised Edition. 107 pages, 13 × 19 cms. New York, Fleming H. Revell Company, 1946. Price $1.25.

Science Since 1500. by H. T. Pledge. 329 pages, illustrations, 15 × 25 cms. New York, Philosophical Library, 1947. Price $5.00.

Functional Anatomy of the Mammal, by W. James Leach. First Edition. 231 pages, illustrations, 15 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1946. Price $2.50.

Speedlights: Construction and Use, by Arthur Palme. 128 pages, illustrations, 14 × 20 cms. Boston, American Photographic Publishing Company, 1946. Price $2.50.

Examination of Industrial Measurements, by John W. Dudley, Jr. 113 pages, tables, 14 × 21 cms. New York, McGraw-Hill Book Company, 1946. Price $2.00.

Talks About Steelmaking, by Harry Brearley. 236, illustrations, 15 × 24 cms. Cleveland, The American Society for Metals, 1946.

CURRENT TOPICS.

Gas-Turbine Locomotive (New Motive Power for Big Coal Customer. (*Coal Age*, Vol. 51, No. 10.)—The coal-fired gas-turbine locomotive—the answer to coal's major competitive problem in the railroad field—should be undergoing on-the-rail tests by June 1, 1948. That is the prediction of John I. Yellott, director of the research program set in motion in May, 1945, by coal companies and railroads comprising the Locomotive Development Committee of Bituminous Coal Research, Inc. Purchase of two gas turbines, each rated at 3,750 shaft horsepower, was authorized by the committee on July 10, 1946, and three builders (American, Baldwin and Lima) are cooperating in the design of the locomotives. Delivery of the turbines is expected shortly after Jan. 1, 1948.

Meanwhile, the coal-handling, pulverization and fly-ash-removal problems solved in the laboratory, Mr. Yellott and his researchers are concentrating on final solution of combustion problems, as well as on early integration of the research results so far completed into a large-scale combustion test unit as the next-to-final step in the complete locomotive equipment design.

With gas-turbine principles and equipment already developed to an advanced state, the job of the Locomotive Development Committee was primarily that of coal handling, pulverization and combustion. This work has included the following organizations and projects:

1. Battelle Memorial Institute—fundamental study of burning pulverized coal under pressure, design and operation of "Vortex" combustor and the burning of a low-ash-fusion coal.

2. Institute of Gas Technology—feeding crushed coal against pressure, partial gasifaction and flash pulverization of coal, fly-ash removal and turbine-blade abrasion and the theoretical study of gas-turbine cycles.

3. Johns Hopkins University—development and testing of the "coal atomizer"; coal handling including study of the "draw-through" system and solution of the problems involved in feeding crushed coal; experience in igniting and controlling pulverized-coal flames in one type of combustor; determination of the efficiency of fly-ash removal equipment and study of pressurized combustion.

4. Purdue University—use of fly-ash to sand rails; effects of sulfur on alloys in the combustor and turbine.

5. Southern Research Institute—development of a system for continuously determining the quantity of coal in a pressurized tank.

In contrast to the conventional locomotive and even the newer diesel, present plans envision the gas-turbine type in ratings up to 8,000 rail horsepower as a double-ended single unit complete with coal bunker and all auxiliaries, including an auxiliary power unit (probably a small diesel) for starting the turbine and facilities for supplying air, electricity and steam for train services. In the initial units, also, the gas turbine will drive a generator or generators through a reduction gear and these generators will supply power to motors on the trucks. Later, it is expected that it will be entirely possible to

drive the wheels directly through gears, as is now done on one steam-turbine locomotive in regular service.

Gas-turbine locomotives are expected to burn less than 1 lb. of coal per rail horsepower-hour without smoke, cinders, fly ash or slag; cost no more to purchase than a diesel and weigh considerably less; need no water except for the train-heating boiler; require less maintenance than the steam or diesel locomotive; need only a two-man crew, with no maintainer; involve only a negligible lubricating cost; produce up to 50 per cent. more power in winter than in summer; have an availability comparable to that of the diesel; and provide for braking either electrically or dynamically.

R. H. OPPERMANN.

Dry Chemicals Extinguish Textile Lint Fires. (*Textile World*, Vol. 96, No. 10.)—Modern Dry-Chemical extinguishers containing a special powder ejected by gas pressure have earned a place in textile mills as an effective means of controlling surface fires in textile fibers.

The extinguishers were subjected to a series of tests on cotton surface lint fires at the Factory Mutual Laboratories as a part of the regular program of research in methods of fire prevention and fire protection. They gave promising results which were subsequently substantiated by trial installations at about 50 cotton mills. Performance was watched over a six-month period during which employees used the extinguishers on actual mill fires, with the usual water-type extinguishers available in reserve. In the opinion of the management of these mills, as well as the Factory Mutual engineers, performance was very satisfactory.

Characteristics. The special powder in the extinguishers is treated so that it will not absorb moisture and become caked. The powder will flow freely even under very humid conditions. It is not subject to freezing or evaporation.

The units are available in 15-, 25-, 140-, and 300-lb. sizes. The 15-lb. size is recommended as being the most practical to handle in fighting cotton surface fires. Its capacity is ample for most situations.

The force for propelling the powder is provided by the release of carbon dioxide which builds up pressure in the main storage container. The 15-lb. unit will propel the powder a distance of about 18 ft. in a fan-shaped spray. The rate of application of powder may be controlled by the operator through a valved nozzle. With the nozzle held open, the discharge will last for 18 to 20 sec. This time appears short, but it is sufficient to cover about 3,000 sq. ft. of surface.

The extinguishing effect of dry chemical powder is due to a combination of properties. First and most important, the powder provides a fire-retardant coating on the fibers. Second, the heat of a fire causes the powder to liberate a certain amount of inert gas. Together these properties mean that a light deposit of powder will prevent rapid flame spread on combustible lints and enable quick control of a surface fire. A small amount of water applied preferably in the form of fine spray—or when necessary by solid stream—may then be used to stop any residual smoldering, such as often accompanies fires involving lint.

Application. Dry powder is best applied by "area flooding." The powder stream should be directed at least three or four feet above the flame from a distance of eight or ten feet. By this procedure, the powder settles and pro-

vides a retardant coating on surrounding surface areas ahead of flash fires. After this application, attention can then be directed to the initial fire without danger of spreading the flame by blowing burning particles about.

Never direct and discharge from this extinguisher at the seat of blaze, as is the usual practice with a liquid-type extinguisher.

Limitations. Acceptance of dry chemical extinguishers for use in textile mills is for surface fires. The powder is not effective against a deep-seated or burrowing fire. Extinguishers having a wetting action should be immediately available to supplement the dry chemical. They will be needed for complete extinguishment of sub-surface fires or residual smoldering of burning lint.

For opening or picking areas, heavy-duty twister rooms, roving frames, jacquard looms, and spinning frames, small hoses with spray nozzles should be provided in addition to dry-chemical extinguishers. For carding, weaving, beaming, and for departments where lint surfaces are usually small and not continuous, pump tanks or, in some instances, water pails will be found to be adequate.

The greatest advantage of dry chemical is the speed with which an operator can cover an extensive area with a single extinguisher. Limiting flash fires to small areas also minimizes the number of sprinklers likely to open and decreases the need for use of larger amounts of water by fire fighters. This control is an important factor, since water damage is frequently greater than the actual fire damage.

Dry chemical powder used has no abrasive or corrosive action on bearings or metal surfaces. The powder will not injure stock even though the materials may be dyed or partially finished. It is not harmful to skin or clothing. These various features make it possible to get back into production faster after a fire has been extinguished.

Location and number of extinguishers depend a great deal on room characteristics and general housekeeping conditions. Average-size opener and picker rooms would usually require to 15-lb. extinguishers. In other departments enough extinguishers should be provided so that one may be located within 75 ft. of each operation or machine.

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